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TIDAL INFLUENCES IN SHALLOW-WATER SOUND PROPAGATION: THE NORMAL MODE EFFECTS*

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Abstract

Many causes of fluctuation in shallow-water sound transmission have been identified in recent years, and may be divided into those that do and those that do not show a tidal influence. The former are reviewed here, with particular emphasis on a number of normal-mode effects. With a single mode the propagation can sometimes peak in frequency near the mode cut-off, this frequency depending on water depth and therefore varying through the tidal cycle. If there are a few modes effective they will combine to form a simple interference pattern, the scale varying symmetrically through the tidal cycle. With several modes the pattern becomes complicated. With large numbers of modes the wave interference is such that regions of sharp focusing can occur. The patterns are not always symmetrical; they are sometimes distorted by the regular tidal changes in the temperature structure and the shear flow. This description shows how the character of the propagation depends critically on the number of normal-modes effective in carrying energy. Other influences on the acoustics which show a tidal variation include internal waves, surface waves and the gross tidal streaming.

Introduction

The propagation of sound has been studied for several years in the shallow waters of the Bristol Channel—see especially⁽¹⁾. One feature of the work is the employment of fixed bottom-laid projectors and receivers, recently covering a wide range of frequencies around 1 kHz. About a dozen different fluctuation mechanisms have been identified.

The purpose here is to discuss the relations among these mechanisms and review the subject

generally. A feature is made of the division into tidal and non-tidal effects. This paper treats the tidal influences; and also concentrates on those which are directly associated with the normal-mode nature of the propagation. A companion paper⁽²⁾ follows on with the non-tidal influences, many of which show a diurnal variation. There is particular reference to those effects associated in some degree with fish. It may be noted that the present paper deals mainly with the moon, whereas⁽²⁾ is concerned largely with the sun.

Both papers draw heavily on the work of several colleagues, especially those named in the references, and their contribution to the investigations is acknowledged with gratitude.

*This paper was first prepared for the British Acoustical Society Symposium on Underwater Acoustic Propagation on 17th October, 1969.

Single Mode Colouration

The colouration phenomenon described here can occur in shallow water when the sea-bed is exposed rock, or rock with a very thin sediment layer superposed. In isovelocity water any normal-mode may be considered as equivalent to two plane waves, one upgoing and one downgoing. At the so-called cut-off frequency for the mode the downgoing wave is incident on the bottom at the critical angle, and on simple theory there is no reflection loss. Just below this frequency the angle is steeper, and there is a large loss by coupling into *longitudinal* waves in the rock. Just above the cut-off frequency the angle is shallower, and there is now a small loss by coupling into *shear* waves in the rock. Transmission over a distance involves many bottom bounces, and so there is selectively good propagation at the cut-off frequency.

Only a single mode is necessary for this effect to be demonstrated. But in general a transmission peak will tend to occur at the cut-off frequency of all the modes. There is a tidal modulation of this colouration effect since the cut-off frequency is inversely related to the water depth.

The evidence for mode colouration is a little indirect, and it is hoped to present it in more detail later. There are two sets of observations in the Bristol Channel area. One set refers to the acoustic energy from underwater explosions, which arrives greatly spread out in time. The ground wave branch comes in first and shows the expected colouration very clearly, at the order of 10Hz for the first mode. Another set refers to the low-frequency spectrum of ambient noise. Under suitable wind conditions this shows the expected series of peaks corresponding to the lowest half-dozen modes.

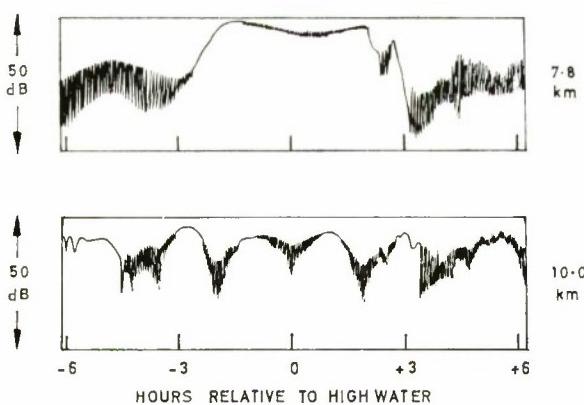


FIG. 1. Modal interference at 2kHz showing signal symmetry over one tidal cycle, a.m. 7th June, 1964.

Interference Patterns With a Few Modes

If there are two modes present they will beat together regularly in space, because their phase velocities are not quite the same. If there are a few modes the resulting pattern will still be fairly simple, and on a relatively large scale. The modal phase velocities, and the scale of the interference pattern too, depend on the water depth. The tidal changes in water depth therefore sweep a small part of the pattern to and fro past the fixed receiver. An example is shown in Fig. 1, taken from a much longer sequence in the work reported in⁽¹⁾.

Interference Patterns with Several Modes

If there are several modes present the pattern will be more complicated. The tidal variation in depth may sweep a few cycles of this pattern past the receiver. This point is illustrated in⁽³⁾, which also demonstrates the two-dimensional pattern obtained by displaying a set of traces for neighbouring frequencies.

Interference Patterns with Many Modes

When there are large numbers of modes it is found⁽⁴⁾ that the mutual interference of these modes can sometimes define surprisingly sharp beams of sound. These beams come together at a series of characteristic ranges, and a series of focal points are formed. The effect may be demonstrated in Wood's model propagation experiments⁽⁵⁾. Wood's results may also be used to show that the characteristic or focal distance varies with water depth in the predicted manner.

Asymmetric Interference Patterns

The changes in the interference patterns as described above are due to variations in water depth, and are therefore symmetrical about the times of high water and low water. Indeed, such symmetrical patterns commonly occur. But there are also mechanisms tending to make the patterns asymmetrical, or skewed in time. One is the shear flow or depth-dependence of tidal streaming, which produces a varying refraction⁽⁶⁾. A second is the tidal introduction of water of different temperature and velocity structure. A third which is closely linked to the second is the possibility of tidal period internal waves. It is difficult to separate the effects of these three mechanisms, but asymmetric and repeating patterns have been found, particularly near springs^(1, 8).

Other Tidal Effects

For the sake of completeness three further tidal effects will be mentioned, although they do not

involve so closely the modal nature of the propagation. Internal waves affect the acoustic propagation, and tend to occur at fixed times in the tidal cycle⁽⁷⁾. (In fact, Fig. 1 includes a rather poor example between +2 and +3 hours). This is because for our shallow water site the criterion for propagation of internal waves involves both the shear flow and temperature structure, which vary regularly through the cycle. Surface waves have marked acoustic influences, and although their amplitude does not depend obviously on the tidal cycle, their effectiveness in causing fluctuations certainly does⁽¹⁾. This is because surface wave effects are relatively much more important near the minimum than near the maximum of the interference patterns. Lastly, the gross tidal streaming produces regular changes in the signal phase⁽¹⁾.

Conclusions

The main purpose here has been to tell the normal-mode story rather than draw detailed conclusions. But this has shown how the characteristics of shallow-water propagation depend critically on the number of effective modes, and information on this point is essential to both

qualitative and quantitative understanding of any transmission problem. See also⁽²⁾.

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NON-TIDAL INFLUENCES IN SHALLOW-WATER SOUND PROPAGATION: THE EFFECTS DUE TO FISH*

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Abstract

The many causes of fluctuation in shallow-water sound transmission which have been identified in recent years may be divided into those that do and those that do not show tidal influence. The latter are reviewed here, particularly those associated with fish. The shoaling of bladder fish during daytime and the dispersal of the shoals at night causes large changes in signal level. A number of different diurnal patterns of attenuation against time have been distinguished and depend on changes in number, type and aggregation behaviour of pelagic fish. The fish attenuation may also affect the mean daytime propagation curve, its seasonal variation and its dependence on wind. Other non-tidal fluctuations include one of some minutes period again probably due to fish, and the seasonal phase changes due to seasonal temperature changes.

Introduction

This is the companion to the paper by D. E. Weston⁽¹⁾ which covered the tidal influences and more specifically the normal-mode nature of propagation. Here some of the non-tidal influences are discussed especially those associated with fish.

Diurnal Effects Due to Fish

Large changes in received signal level may often be noticed at sunrise and sunset, and were first

discovered in 1963⁽²⁾. The patterns were attributed to fish largely because of the timing relative to light intensity and the knowledge that fish shoals break up when it gets dark and reform when it becomes light. The scattering and absorption of sound by the fish depends on their degree of aggregation; this is particularly important for pelagic fish having swim bladders. At night the fish swimming as individuals can produce a high overall attenuation. In the day time when they are packed into shoals there is acoustic interference between the scatterers, and the attenuation they produce is less.

*This paper was first prepared for the British Acoustical Society Symposium on Underwater Acoustic Propagation on 17th October, 1969.

A systematic series of multifrequency amplitude fluctuation experiments were carried out in the Bristol Channel at regular intervals between May 1967 and September 1968⁽³⁾. A sequence of pulses of 4s duration at frequencies between 700 Hz and 3.5 kHz was transmitted every 100s, and received at ranges of 23 and 137 km.

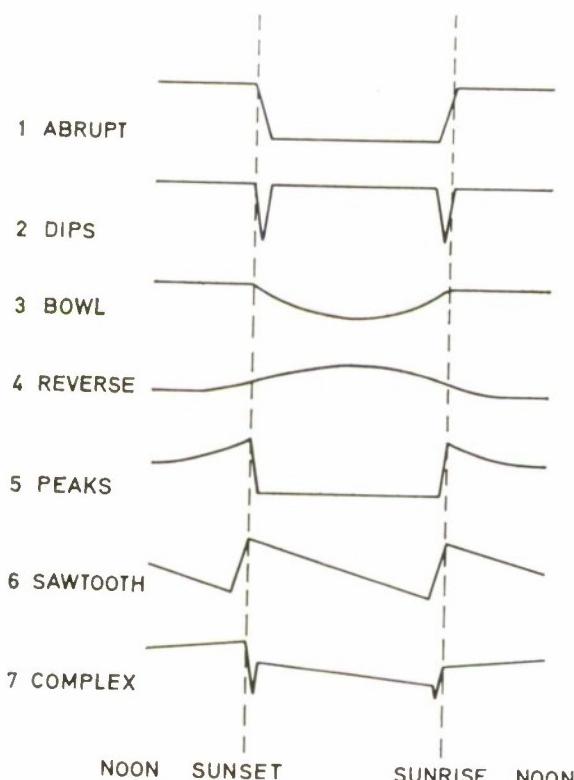


FIG. 1. Schematic representation of attenuation patterns due to fish.

Seven different diurnal patterns of attenuation against time have been distinguished⁽⁴⁾ and a schematic representation of these patterns is shown in Fig. 1. It is convenient to show patterns as centred about local midnight rather than mid-day. The first three patterns are the simplest and most common. Pattern 1 is an abrupt drop in signal level after sunset, often between 15 and 25 dB, followed before sunrise by a similar abrupt rise in level. Pattern 2 is a dip in signal level of between 10 and 20 dB, after sunset and before sunrise. Pattern 3 is a bowl-shaped gradual change in signal level of between 5 and 15 dB giving a reduced signal level at night.

The character and magnitude of the patterns are very variable and are due in part to changes in number, type and aggregation behaviour of pelagic fish. There may also be a contribution from

bottom-living fish which may swim upwards in the water column around twilight. In addition, pelagic fish will often assume a shallower depth near dusk. Acoustically the depth of the fish is important for three distinct reasons. First, the bladder resonance frequency is a function of depth. Secondly, there is the Lloyds mirror interference effect occurring near both the surface and the bottom. The acoustic pressure is reduced, the fish are partly decoupled from the acoustic medium and the attenuation is reduced. Thirdly, the sound velocity structure may channel the sound, usually in the lower half of the water column. This is important for the 137 km path, particularly in the summer months, and deep fish can then have much more effect than shallow fish.

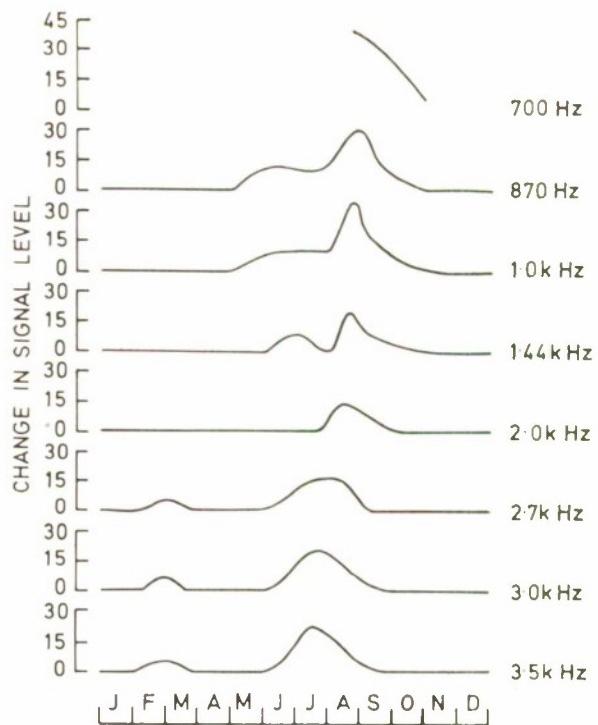


FIG. 2. Seasonal dependence of diurnal level changes over 23 km path.

The amplitude of the change in signal level for each pattern has been plotted against the time of year in Fig. 2 for the short range 23 km path. The pattern may involve an increase or decrease in signal level at night. The main effects over this path occur between July and September, the higher frequency transmissions being affected about a month earlier than the lower frequencies. The maximum observed attenuation of at least 45 dB occurred at 700 Hz, which is the lower limit of the

measurements. But it does seem as if the effect peaks at this frequency, with a Q-factor of about 2. A bladder resonance of 700 Hz corresponds, with a few reasonable assumptions, to a fish length of 24 cm, almost certainly the Cornish Pilchard. There is a second frequency peak at about 3.2 kHz, corresponding to a 5.3 cm length, with no obvious fish candidate responsible.

From the measured attenuation and frequency it was possible to estimate the mean numbers of fish in the 24 cm category as at least 0.12 per m² of sea surface with mass about 12 gm per m², or 110 lb. per acre.

For the 137 km path the attenuation patterns are not limited to the summer months and there are no marked frequency dependence effects as for the 23 km path.

Seasonal Variation in Propagation

It is possible that the diurnal variation of the fish effect is not a full-depth modulation, *i.e.* there may also be some fish attenuation remaining. This helps to explain the observed characteristics of shallow water propagation, and is partly supported by the seasonal dependence of the daytime transmission. The increased losses in the summer are apparently due to a mixture of thermal and fish mechanisms⁽³⁾.

Wind Attenuation

High winds, or rough seas, attenuate the signal level, affecting the higher frequencies first⁽⁵⁾. It has been observed at times that the lower frequency transmissions are attenuated first in the daytime when the diurnal fish patterns are present. This is presumably because the fish shoals have been dispersed by rough seas and this has caused the attenuation.

Fast Fluctuations

Another fluctuation effect occurs in the summer daytime over the short range path^(2, 6). During the night the envelope of the pulses is smooth, but during the day the amplitude variation is considerable and the envelope is rough, with a

typical period of some minutes. The timing of the effect is closely allied to the attenuation patterns, suggesting that the cause is again fish. This effect occurs over the whole frequency range, and is most pronounced in August.

Other Non-Tidal Influences

Another possible cause of fluctuation, not connected with fish, is a diurnal thermal effect. With our shallow-water geometry this is expected to be small however.

This paper has dealt only with amplitude fluctuations, but there are also phase effects. The seasonal change in mean temperature of the water affects the phase delay, which is least in the summer due to the higher temperature and sound velocity.

Conclusions

The breaking up of the shoals of bladder fish can cause very large night-time falls in signal level. Such fish attenuation may also affect the mean daytime propagation curve, its seasonal variation and its dependence on wind. In general (see also⁽¹⁾) attention is drawn to the large variety of causes of shallow-water fluctuation, and the consequent difficulty in understanding and predicting transmission loss.

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A MACHINE FOR TRACING PROFILES OF PROPELLER BLADES

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Abstract

A machine is described which can be used for production of accurate 1 : 1 tracings of propeller or similar blade forms. It is capable of tracing profiles either on plane, cylindrical or conical sections with equal facility. The machine has been in use in the Admiralty Research Laboratory for some time and has proved very successful.

Introduction

The inspection of profiles such as those of propeller and turbine blades has presented many problems in the past and a number of methods have been developed to solve these problems. In general it can be said that most methods of inspection have been developed for ensuring reliable production of relatively large quantities and have usually resulted in complex expensive machines. Where experimental blades are required in small quantities, as in the Admiralty Research Laboratory, it is not economical to purchase such inspection machines even assuming that any one machine would satisfy all experimental requirements.

Consideration of A.R.L.'s requirements led to the design and manufacture of a comparatively simple machine which has proved very effective and which is the subject of this article. Blade profiles may be related to any required section which can be plane, normal to a radius, cylindrical at given radii or, as is required by the fluid dynamics group in A.R.L., sections determined by the flow lines through the propulsor which in effect are sections taken on conical surfaces, the angle of the cone being different for each radius section. As far as was known this latter requirement had never previously been requested and no existing machine was capable of satisfying it.

Specification of Requirement

It was considered that the most convenient method would be to produce a tracing of the profile of any section of the blade which, after suitable magnification, could be compared directly with a master drawing. In many cases these master drawings were used directly in the manufacture of master blades from which experimental sets were copied and consequently such an inspection method would serve to provide a check on the accuracy of the machine used to make the blades. The sizes of blades to be accommodated were up to six inch tip radius and five inch chord.

Description of the Machine

After preliminary design studies and some experimental investigation it was decided that the machine should consist of a main shaft mounted in an air bearing system which would provide freedom to rotate and to move axially. The blade or complete rotor was to be mounted at one end of the shaft while at the other end an attachment would carry a block representing the required section, for example a segment of a conical surface of any selected cone angle and radius.

The profile tracing attachments were to be carried on a slideway at right angles to the axis of the shaft and an air bearing of rectangular section was chosen for this. These attachments were arranged so that at one end a stylus could trace around a blade surface and be held perpendicular to a tangent at the point of contact. At the other end a special cutting stylus was provided which could cut through the surface layer of a plastic based tracing medium, taped down into close contact with the surface representing the section. The inspection of single blades necessitated

provision of radial adjustment to enable the blade to be set at its correct operating radius. The block fitted to the other end established the section of the blade to be inspected, a suitable range of blocks being provided to cover the required number of sections. A design figure of 20 - 25 lb. was adopted for the maximum weight of the blade plus its mounting, with a similar figure for the section block at the other end of the shaft.

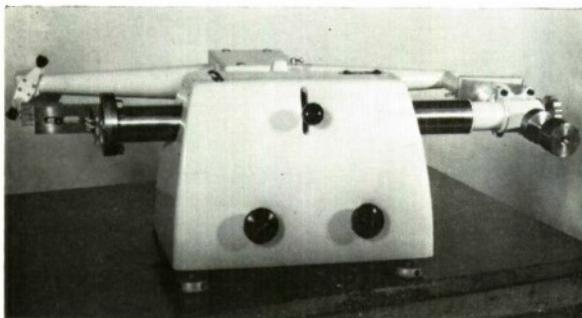


FIG. 1. Blade profile tracing machine—front view.

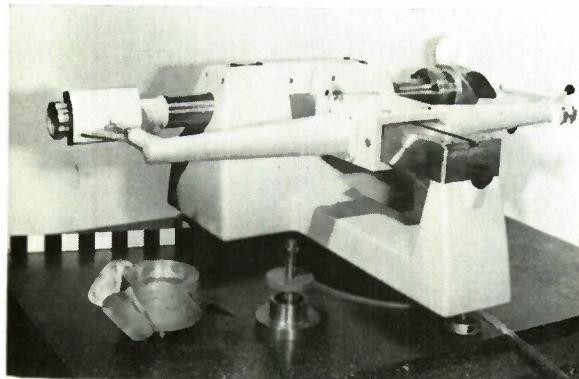


FIG. 2. Blade profile tracing machine—back view.

The Finished Machine

The final appearance of the machine is shown in Figs. 1 and 2 which illustrate the main features while Figs. 3 and 4 show the blade tracing stylus and the cutting stylus ends in greater detail. Fig. 3 shows the mounting arrangement for a single master blade, using an adapter plate and bracket. When a complete propeller or rotor is required to be checked a hub fixture can be fitted to the shaft flange with centreing location ensured by a spigot.

At the other end, Fig. 4, is the mounting system for the radius blocks with an adjustable counter weight to compensate for the weight of the block and blade. The cutting stylus is mounted in an adjustable quadrant unit calibrated in angular degrees to enable the stylus to be set normal to the surface of the radius block before making a tracing.

The tracing medium used for recording the profile is K and E *Stabilene* scribe coat supplied by Ilford Ltd. This material is a clear polyester film base with an opaque coating on one side available in several forms. The type chosen for use with this machine is known as white on rust which provides a good contrast between the scribed line and the surface, thus enabling rapid inspection of the quality of the trace before



FIG. 3. Blade mounting end.

removal from the machine. The cutting stylus is in the form of a truncated cone whose flat top is .002 inch in diameter. When this stylus is correctly set so that its axis is normal to the surface of the tracing medium it acts as an omni-directional cutter, which removes the coating along its path and exposing a transparent trace which can be projected at a suitable magnification for comparison with a master drawing.

Air for the bearing system is supplied from a 100 p.s.i. line through a reducing valve and filter at a final pressure of 40 p.s.i.g.

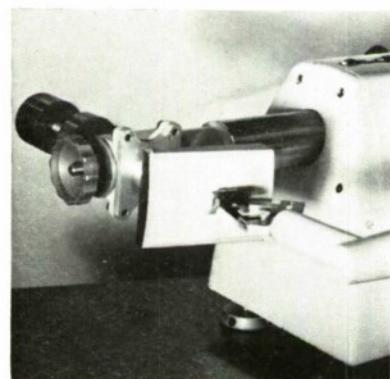


FIG. 4. Profile recording end.

Setting Up

In order to achieve accurate results from the machine the initial setting up is of the greatest importance. The principal requirements are that



FIG. 5. Samples of section blocks.

the tips of the two styli should lie on a straight line precisely parallel to the axis of the shaft and located to move in the radial plane established by the stylus carriage slide. To aid the establishment of datum lines on the tracing of a profile the machine is set up on a surface table with the shaft axis parallel to the surface. The surface table can thus be used as a reference plane from which the datum lines can be determined.

The machine is also slightly tilted forward to bias the stylus carriage toward the shaft. The cutting stylus is spring loaded to give the correct

pressure for cutting the surface layer of the tracing medium and a ball ended skid alongside the stylus must be adjusted to carry the principal load of the carriage when the stylus has deflected .005 - .010 inch.

At the other end the radial setting of the tracing stylus has to be adjusted so that the tip rotates on a point in space when the stylus arm is rotated on its axis. For average sections the accuracy of tracing normally achieved is of the order of $\pm .001$ inch.

Conclusion

The profile tracing machine described has proved particularly successful in meeting A.R.L.'s requirements for the checking of experimental blade profiles. It has proved valuable in rendering assistance to contractors in the checking of samples from a production run of blades for a torpedo propulsor.

Interest in this machine has been expressed by the Fluid Dynamics Division of the National Engineering Laboratory. A request has also been received from A.U.W.E. for the facilities to be employed in checking a new series of torpedo propellers from the masters to periodic checks on production batches. An application for a provisional patent has been made.

If the requirement exists it appears feasible to produce a larger version capable of dealing with propellers or blades considerably larger than the present scale.



ENVIRONMENTAL EFFECTS AND RESIDUAL STRESS

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In this paper I would like to explore two areas where environmental effects interact with residual stress and give detrimental results.

One is where moisture together with small amounts of contaminants can come into contact with a stressed metal surface. The second is when certain steels are exposed to low temperatures. The results in either case can be a failure without warning—a rupture endangering people or adversely affecting the reliability of machinery or an engineering structure.

Residual Stress

For those not too familiar with residual stresses it may prove useful to review briefly what residual stresses are, how they may be avoided or eliminated, and how they are commonly measured.

Residual stresses are generally thought of as stresses trapped in a metal from some process or procedure involved in its manufacture, as opposed to normal stresses which arise in use of the metal. Residual stresses may arise from almost any metal working, forming, casting, or heat treating operation⁽¹⁾. Machining and grinding also contribute to residual stresses in the surface of a metal. One of the most common sources of residual stresses is welding. The stresses produced by welding have been thoroughly evaluated⁽²⁾.

Residual stresses have generally been considered detrimental, as witness the widespread adoption of palliative measures aimed at their elimination or reduction. Residual stresses may, of course, also be desirable and beneficial. One of the most widely used examples of intentionally induced residual stresses involves putting the surface metal of shafts, axles, etc. in compressive stress to improve fatigue life. Methods used to achieve this include controlled peening⁽³⁾, rolling, or even heat treating.

Residual stresses may be lessened markedly by the well-known and widely specified use of stress-relief annealing. Boiler and pressure vessel codes call for this annealing after fabrication. Annealing or even ageing of castings, and stress relieving prior to machining are often used in order to ensure dimensional stability. This relief may take the form of conventional heating in furnaces at around 1,200°F, using the vessel itself as the furnace (insulated and heated internally by hot gases), local application of heat by induction, electrical resistance, or by gas-fired torches, or even the special low temperature stress relief⁽⁴⁾ which is aimed at structures too large to be put in a furnace (e.g. ships, tanks, penstocks, large pressure vessels). An example⁽⁵⁾ is the reduction of a 42,000 psi peak tensile stress in a $\frac{3}{4}$ inch steel butt weld to 6,000 psi tensile by use of this 350°F procedure.

Other methods which relieve residual stresses include peening of surfaces (this has obvious limitations in depth affected, but improves the critical surface metal) and by slight deformation of the metal beyond the yield as may occur locally in hydrostatic pressure testing⁽⁶⁾. The section on "Relief of Residual Stress" in the ASM Metals Handbook describes these methods in more detail.

Residual stresses may be determined by any of three methods:

- (1) Severing of stressed component so that dimensional change provides a measure of residual stress, e.g. springing apart of slit tube.
- (2) Use of strain gauges on an area which is then carefully removed from restraint of surrounding metal.
- (3) X-ray diffraction—a non-destructive means of measuring directly the amount of lattice strain in a very small area⁽⁷⁾.

1. Corrosion

Most corrosion action can be readily assessed as being caused by corrosion because of the visible corrosion products such as rust (where ferrous metals are involved) or the voluminous white oxides and hydroxides from aluminium or zinc. These visible signs are not usually associated with stress corrosion. Where there is a combined effect of corrosion and stress the action is much more severe than either acting alone⁽⁸⁾. This stress corrosion cracking, as it is called, can give an apparently brittle rupture (no deformation or stretching) of a part of an otherwise normally ductile metal.

The classic and most common of stress corrosion cracking examples is the "season cracking" of brasses (so called because it resembles cracking in unevenly seasoned lumber). This attack of brasses requires the presence of a specific corrodent, ammonia. The source of ammonia type compounds in a marine environment may be decaying animal and vegetable matter, bird droppings, or other excreta⁽⁹⁾.

A length of 70Cu-30Zn brass tubing failed by the cracking shown in Fig. 1. Note the extent of crack opening as a measure of the tensile stress involved. In this instance the stresses were residual tensile resulting from cold forming of the tubing⁽¹⁾. The tubing was stored in an open shelter and the stains from bird droppings are a clue to the source of the corrosive. Cracks originated in the stained areas. Examination under the microscope showed fine branched cracking typical of stress corrosion, Fig. 2.

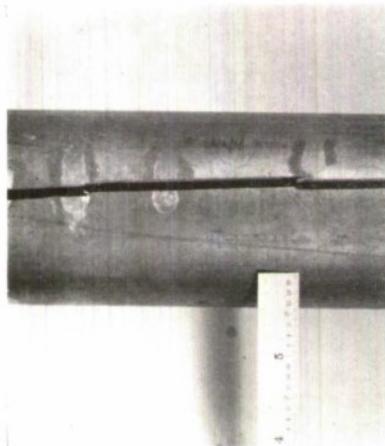


FIG. 1. Cold drawn 70 - 30 brass tube showing season cracking. Note the discontinuities in the crack at the bird droppings.



FIG. 2. Microstructure of brass tube in FIG. 1, showing typical intergranular "season cracks". (X200).

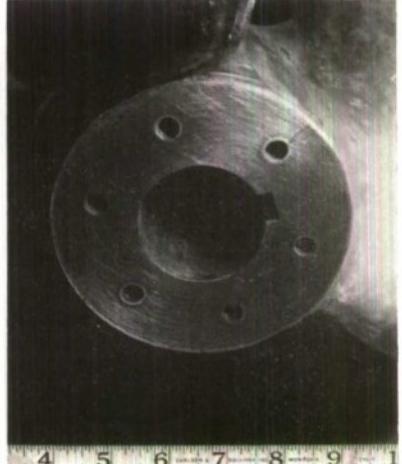


FIG. 3. Cracked high strength brass propeller.

Another example⁽⁹⁾ encountered was the ship propeller shown in Fig. 3. This was a high strength brass propeller (58% Cu, 2% Al, 1% Fe and 2% Mn) which cracked between the bolt-holes of the thick hub. Because of the size of the hub it was believed that only residual stresses from casting were involved. While it appeared that the cracking occurred while in contact with sea water, a more likely possibility was that seagull splatter hit this area when the propeller was on the dock-side before installation.

A totally different environment is that occurring inside superheater tubes⁽¹⁰⁾. For those not familiar with marine propulsion plants, Fig. 4 shows the arrangement in a boiler with the superheater tubes tucked in between generator tubes. The superheater unit is more than 30 tubes high. The tubes which cracked in two batches about a month apart, three tubes on each occasion, were in the innermost row of Fig. 4. This cracking was followed by a complete and expensive retubing of the superheater unit. The type of cracking is shown, Fig. 5, with rupture occurring at the inside of the bends. Examination of samples from these tubes showed the fine intergranular cracking indicating stress corrosion, Fig. 6.

There are not many contaminants or chemicals readily available in a boiler environment which will attack steel. One of these is sodium hydroxide or caustic. Careful analysis of surface residues did in fact confirm the presence of caustic (as much as 0.5 grams per 100 feet). The presence also of phosphate indicated the likely source as carry-over during high rates of steaming.

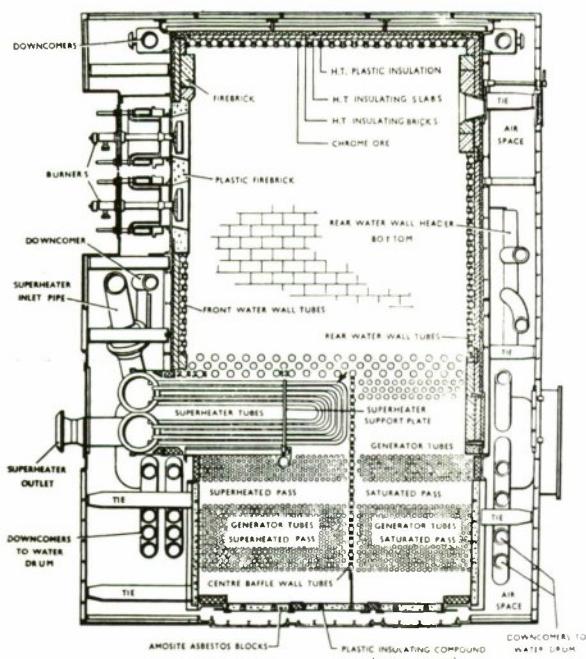


FIG. 4. Section through a boiler showing the superheater tube nest tucked in between generator tubes.



FIG. 5. Part of failed inner row superheater tube showing rupture on inside of bends (cracks initiated in bore of tube).



FIG. 6. Intergranular cracking typical of stress corrosion cracking. (X200)

TABLE I.
Strain Gauge Determinations

<i>Tube Sample</i>	<i>Residual Stress</i>
E30 inside bend, in bore	26,000 psi tensile
exterior	14,000 psi compressive
E30 straight length, in bore	15,000 psi tensile
E row tube (random sample)	
inside bend, in bore	8,000 psi tensile
exterior	7,000 psi compressive
E row tube (random sample)	
straight length, in bore	17,750 psi tensile
exterior	19,200 psi compressive
E23 outside bend, exterior	16,000 psi tensile
in bore	10,000 psi compressive
inside bend, in bore	19,000 psi tensile
exterior	15,000 psi compressive
E row tube (random sample)	
inside bend, exterior	15,600 psi compressive
outside bend, exterior	2,400 psi tensile
E row tube (random sample)	
inside bend, exterior	27,000 psi compressive
outside bend, exterior	0 psi

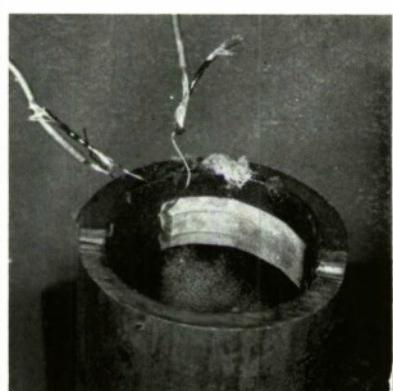


FIG. 7. SR4 strain gauge attached to inside of bend of superheater tube bore for residual stress determination.

The stress present was established by the use of strain gauges mounted in several locations as shown in Fig. 7 and Fig. 8. These strain gauge measurements detected in the "as received" straight lengths, residual compressive hoop stresses on the exterior and residual tensile hoop stresses in the bore. Tube bending resulted in enhancement of the residual tensile hoop stresses in the bore on the inside of the bend, and a partial relief of

the residual tensile hoop stress in the bore on the outside of the bend. Results obtained are given in Table 1.

Corrosion cracking occurred at the highest tensile stress location, *i.e.* tube bore on the inside of the bend.

It was established that a stress relief specified to be carried out at 1200°F had not been done. As an example, one hour at 1200°F will lower a

62,000 psi residual in a low alloy steel (SAE 4130) to 1900 psi⁽⁶⁾. These failures would not have taken place had the residual stresses been appreciably reduced.

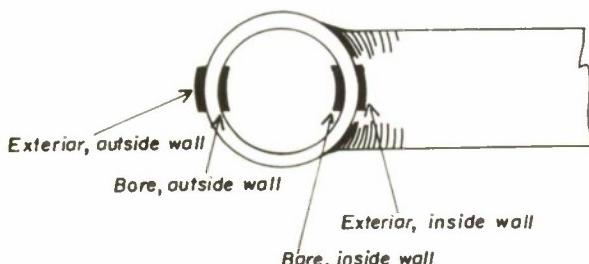


FIG. 8. Drawing showing locations of strain gauges used in determining residual stresses.

It was not clearly established why the only failures were in the E row, unless it required that particular amount of bending stress by cold work to exceed some type of threshold.

The next problem⁽¹¹⁾ is one where a fine line might be drawn between what is a service stress and a residual stress. It's a situation where a residual stress resulted from conditions in service. It can be defined as a residual stress because the stress remains in the tube following exposure to service conditions.



FIG. 9. Corrosion-fatigue crack inside a boiler tube.

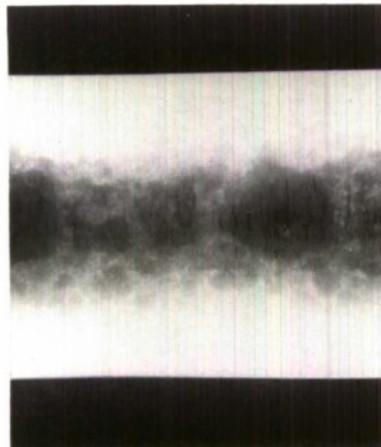


FIG. 10. Radiograph of a tube similar to that shown in Fig. 9 showing numerous corrosion-fatigue cracks (X2).

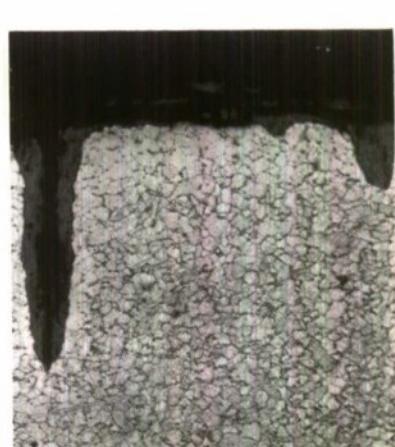


FIG. 11. Corrosion pit typical of early stages in those which propagated as corrosion-fatigue cracks. (X80).

Examination of a boiler tube failure in a ship which had seen many years' service showed that failure was the result of corrosion-fatigue. The type of crack in this and other tubes is shown internally in Fig. 9 (after cleaning). A radiograph of another tube shows several cracks of this type, Fig. 10.

In one ship following discovery of one leaking tube, two other tubes were found by radiography to contain cracks. Another cracked tube was later found in another similar ship. Considerable internal deposit was noted in these tubes as well as some internal corrosion. These cracks were between 10 and 34 inches up from the mud drum, and initiated on the water side.

Sections were cut from some of the tubes and cracks at various stages of advancement were found, Fig. 11. The pits from which the cracks initiated appeared to be wedge-shaped rather than having round bottoms—suggesting that they formed in highly stressed metal.

The main cracks were clearly corrosion-fatigue.

As part of the investigation, one of the tubes in which radiography detected cracks had two strain gauges mounted on it, one in the bend 17 inches above the mud drum, the other just above the bend. A cut was made just below the upper bend (some four feet to five feet higher), resulting in the tube springing away approximately 3½ inches at the end. The strain gauge in the bend indicated that a residual stress of 32,000 p.s.i. was present. A residual tensile of 25,200 p.s.i. was in the tube above the bend.

Because of sagging, a number of other tubes were also removed. Strain gauges gave a maximum

residual tensile in these non-cracked tubes of 13,500 p.s.i.

The only cracks were confined to the fire side (inside) of the tubes at the lower bend, where the maximum longitudinal stress would be, and was in fact found.



FIG. 12. Photograph of one failed and one apparently sound actuator valve seat bush. Fracture area is at base of threaded portion.

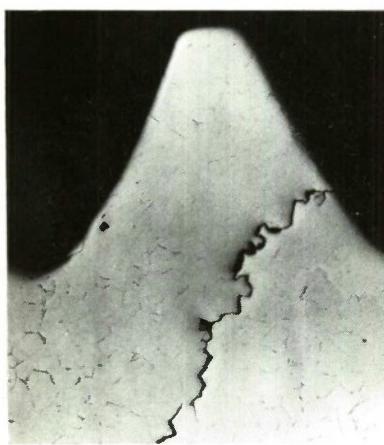


FIG. 13. Stress corrosion cracking extending into valve bush (of Fig. 12) from threads (X20).

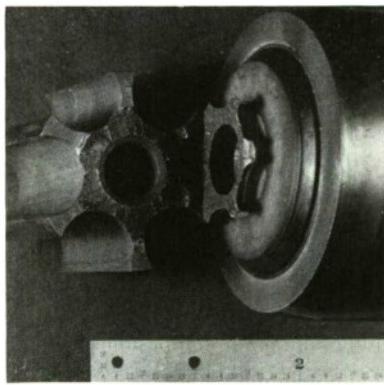


FIG. 14. Pilot valve feather which failed by stress corrosion cracking.

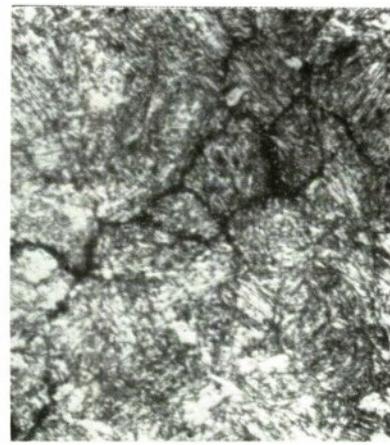


FIG. 15. Intergranular corrosion cracks which initiated failure of pilot valve feather of Fig. 14 (X400).

A mechanism suggested was that:

- Certain tubes overheated because of internal deposits;
- These tubes tried to elongate by expansion but were restrained by cooler neighbours;
- The tubes "upset";
- On cooling, these tubes were under tensile stress which was greatest on the fire side.

It may be noted that upsetting could result from only a brief high temperature exposure. The resulting residual tensile stresses would not be relieved by normal service.

When the boiler was shut down it would take only a slightly corrosive environment (such as a temporary lapse in boiler conditioning, or oxygen ingress) to form pits, and under the action of residual stress and fluctuating service stresses these, in time, would result in the corrosion fatigue cracks.

The main approach to avoiding future trouble was by removal of internal deposits.

Another instance⁽¹²⁾ where we believe only residual stress could be the energy source for stress corrosion cracking was in several failures of superheater valve parts, shown in Figs. 12 - 16 inclusive. These were of hardened (Rc40) martensitic stainless steel (type 414 - 12Cr - 2Ni).

These brittle appearing failures were not associated with stress-raising notches. The environment was steam or condensate and did not likely have any chlorides present (or austenitic stainless steel parts in these valves might have been expected to crack—they didn't). A search of the literature revealed that other investigators had reported failure of hardened martensitic stainless steel in pure hot water. The parts involved in our investigation were exposed to insignificant stresses in

service. The only possible conclusion was that high residual stresses—probably from heat treatment—were sufficient to cause cracking.

Because the environment couldn't be changed, we looked to other materials which would resist the environment (e.g. Ni-plated steel, Inconel). In the interim, a regular annual NDT programme has picked up defective components (in 16 safety valves seven defective parts found).

II. Low Temperature

The second area where environmental effects and residual stresses can cause trouble is in certain steels at below normal temperatures.



FIG. 16. Cracking in superheater valve feather (outlined by magnetic particles).

If a series of specimens are tested under rapid loading in a notched bend test (e.g. Charpy V-notch) at a series of decreasing temperatures, the result will be a curve, Fig. 17, showing the decreasing ability of the steel to absorb energy at lower temperatures. This is referred to as a lack of notch-toughness and can be a serious engineering limitation in steels. This lack of notch toughness may be detected by any of a variety of tests described in the technical literature⁽¹³⁾. There has also in recent years, grown up a science of fracture mechanics by which it is possible to predict a critical crack size for propagation of a brittle fracture⁽¹⁴⁾. We know that the composition and condition of the steel are important in this behaviour. For example, the steels are generally of moderately high carbon, and the manganese content is decidedly on the low side. Other factors such as grain size and mill finishing temperature also affect steel quality in this regard⁽¹⁵⁾.

This is an area where residual stresses may or may not be involved. Nevertheless, there have been a considerable number of these failures at low temperature, *i.e.*, apparent spontaneous fractures, which allow of no feasible explanation other than that they were caused by residual stresses introduced during fabrication.

This phenomenon—lack of notch toughness, or brittle behaviour of steel at low temperatures—was given international prominence with the many failures of Liberty ships in World War II. In January 1943, some 500 Liberty ships were in service and 10 had suffered hull fractures serious

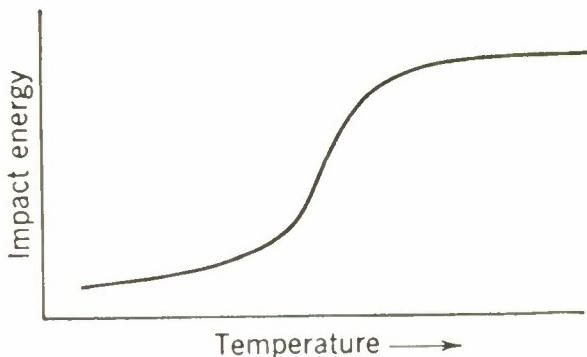


FIG. 17. Decrease in energy absorption with lower temperature.

enough to endanger the vessel⁽¹⁶⁾. A newspaper clipping of 4th March 1956 (Fig. 18) indicated that these failures were still occurring more than 10 years later. One of the early failures is shown in Fig. 19⁽¹⁷⁾. In mid-January 1943 a T-2 tanker lying quietly at her outfitting dock suddenly broke in two. Maximum stress in the top skin, *i.e.* deck, was under 10,000 p.s.i. The role of residual stress may be gathered from the following portion of the investigation conclusion:



FIG. 18. A newspaper clipping indicating failures still occurring more than 10 years later.

"an accumulation of an abnormal amount of internal stress locked into the structure by the process used in construction together with an acute concentration of stress caused by defective welding . . ."⁽¹⁶⁾

Research following these failures in World War II clearly established that:

- (a) failures generally occurred in cold weather and heavy seas
- (b) failures in calm water were at temperatures about 15°F lower than for heavy weather casualties
- (c) these steels had normal tensile properties, i.e. there was no correlation between tensile properties and service behaviour
- (d) the steels in which fractures initiated were those in which Charpy V-notch was below 10 foot pounds at failure temperature, i.e. there was good correlation between Charpy V-notch and service behaviour.

There was no doubt that the type of steel used was a major factor, so also were weld defects and sharp corners in hatches as initiating points of high stress.



FIG. 19. Tanker S.S. Schenectady which broke in two while lying quietly at outfitting.

Currently specifications for steel plate for shipbuilding require that it have adequate notch toughness to pass a notched bar impact test at a temperature below that expected in service.

The rôle of residual stress was debated by some investigators. There is, however, no doubt that residual stresses arise from welding by two mechanisms:

- (a) from freezing of the molten pool and shrinkage, and
- (b) from upset in the adjoining plate.

Residual stresses obviously exist, and have been measured as being close to the yield point of steel.

The paper by Greene in the *Welding Journal*⁽¹⁵⁾ provided a useful clue:

Tests were made with large welded plates, three feet square, with sharp notches cut across the weld at midlength of the plate. These plates were static loaded in the brittle temperature range for this steel. The results: low temperature stress relieved plates could carry four times as much load as the as-welded. In addition, one of the as-welded specimens broke spontaneously before any load was applied—the conclusion was that "this failure without load could be caused only by residual welding stresses".

The connection between this research and the T-2 tanker rupture (Fig. 19) is suggestive.

One investigator⁽¹⁸⁾ reported four instances of spontaneous fracturing of ships while under construction. In one of these there was no external load except perhaps that due to the weight of the structure itself and a maximum nominal tensile stress of only 2000 p.s.i. An appreciable time elapsed between completion of welding in the structures and the time of fracture. The author was of the opinion that "the only conceivable sources of stress present to initiate and propagate the cracks were the residual stresses resulting from the welding process".

Another investigator⁽¹⁹⁾ who has had considerable experience with the low temperature stress relief process, and advocates its application as insurance against the contribution to failure which residual stress can contribute, makes the following statements:

"Design is certainly the most important factor for ensuring safety, but it is equally wrong to assume that residual stress may never produce failure. There are too many authenticated cases, wherein completely unloaded objects have cracked during a cold night, to ignore them. Ships have failed at calculated stresses of less than 10,000 p.s.i. It is difficult to conceive that a residual stress has not contributed to such a failure".

There have also been a considerable number of non-ship failures⁽²⁰⁾.

A description of one example of this type of failure follows:

Failure of three empty oil storage tanks in Europe in 1952 was reported. The tanks were 144 feet diameter and 45 feet high. The plates ranged from $\frac{1}{2}$ inch for the lower course to $\frac{1}{4}$ inch at top. The steel had a tensile strength of 60,000 p.s.i. and elongation of 20% in 8 inches.

The welds had been chipped flush on the inside of the tank and extensive heavy hammering had been done to correct distortion. The tanks had been completed for about three weeks and were still empty when the temperature fell to 25°F. The next morning a large number of cracks extending across the welds were discovered. These cracks extended about three inches into the plates. "Residual and thermal stresses provided the energy necessary to crack the steel".

As well as these numerous tank failures, there have also been failures of welded bridges. These occurred at temperatures generally below 10°F and as low as -20°F and -30°F. An example is the failure of the Duplessis Bridge at Trois Riviere in Quebec at -30°F. The rôle of residual stress was not defined but the steel was definitely of inferior toughness (e.g. three to six foot pounds at 100°F).

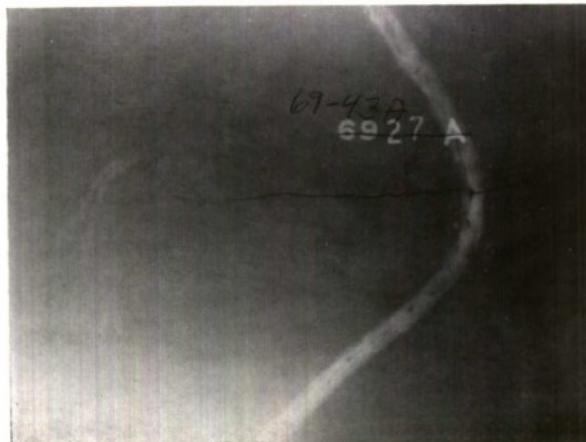


FIG. 20. Radiograph of crack originating in weld in 12-inch pipeline.



FIG. 21. Photograph of completed repair indicating location at saddle.

In our own experience, an unusually cold winter (January 1969, with temperatures to 4°F) resulted in cracking of a 12 inch pipeline in the manner shown in the radiograph, Fig. 20, taken to establish the extent of the cracking prior to repair. Because of the necessity of getting the line back in operation immediately, the repair was completed as shown in Fig. 21 and no further investigation was possible. The fact that the crack was centred about the weld, indicates a strong possibility that residual longitudinal stresses in the saddle weld contributed to the cracking.

It is only fair to point out that other investigators are not prepared to assign to residual stresses the primary rôle that these examples suggest. They tend to the consensus that residual stresses act in conjunction with thermal stresses, load stress, excessive cold work and at temperatures where the steel tends to behave in a brittle fashion.

In summary, this has been a brief review of a number of situations where failure has resulted from the interaction of residual stresses with an environmental factor such as corrosion or low temperature. An appreciation of the mechanisms involved in such failures, suggests how similar problems may be avoided in future.

Acknowledgements

The author is indebted to his associates at D.R.E.P. (formerly P.N.L.) whose work is incorporated in parts of this article.

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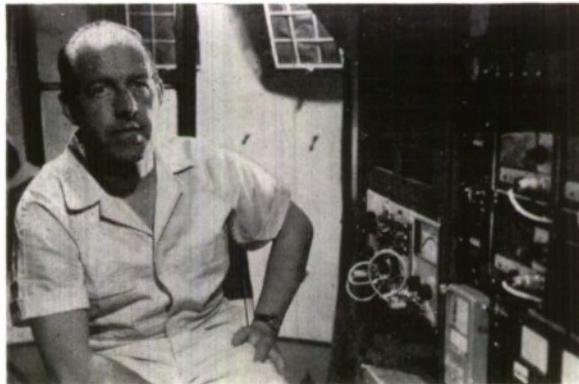
A. B. WOOD—MEMORIAL

A plaque in memory of Dr. A. B. Wood, O.B.E., together with a copy of his memorial volume of *J.R.N.S.S.*, is to be placed in the Saddleworth County Secondary School. The unveiling of the plaque by Sir Charles Goodeve will take place in the Spring of 1970, in the presence of Mrs. Ethel M. Wood, colleagues of the late Dr. Wood and members of the Saddleworth Urban District Council.



THIRTY DAYS OF DRIFTING

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The author, in the Scientific Control Center.

The forward hatch of *Ben Franklin* opened at 0758 hours on the 14th August, 1969, 300 miles south of Halifax, Nova Scotia, after closing at 2030 hours on the 14th July, 12 miles south-east of West Palm Beach, Florida. In all, we drifted close to 1,500 miles adding up the mileage between our fixes; to this must be added the local perturbations between fixes.

As we drifted along with the mass of the Gulf Stream there was no sensation of movement, observation through the viewing ports produced no sensation either as we were moving in step with the plankton. Most of the time was spent around 600 ft where we tried to ride the 18° isotherm, the boat being trimmed for this level. South of Cape Hatteras where the water depth permitted, we made a number of excursions to the bottom, the deepest being to 1,850 ft. *Ben Franklin* is limited to 2000 ft with a safety factor of 2. In two places the half knot bottom current was too strong for the boat and she could not be held stationary. It was here that movement was all too evident as we appeared to be flying over the bottom at a very fast rate.

Handling the boat presented no problems; once the hull temperature had stabilized and the water and salinity remained constant she could be trimmed for neutral buoyancy at any depth, just like a giant Swallow float. The occasional presence of internal waves was visible from the recording depth gauge, a phenomenon new to Jacques Piccard whose previous submersible, *Auguste Piccard*, was operated in the fresh water of a Swiss lake.

We spun out of the main stream only once and had to be towed back in; this was off Charleston, South Carolina. Our position relative to the core of the Gulf Stream was obtained by the U.S.S. *Lynch*, an oceanographic research vessel which continuously zig-zagged across the Stream taking expendable bathythermograph readings. We went to the bottom off Charleston in a position close to the north wall of the Stream, passing through the wall during our descent to the bottom. From here we could not regain the main Stream and had to surface to be towed back into the core by *Privateer*, our mother ship. At this time the hatches were not opened during the 12 hours that we were on the surface.

The distance travelled was further than expected based on the available data. Our biggest surprise was the speed of the current north of Cape Hatteras. We averaged about 3·8 knots for a number of days and for a short period appeared to travel at over 4 knots. This was unexpected as speeds of this magnitude had not been measured before in the area although some theoretical work at Woods Hole Oceanographic Institute had indicated that such speeds were possible. In the Straits of Florida where we had expected the high speeds we averaged about 1·8 knots. Towards the end of the mission our speed fell again and for the last three days before surfacing we were heading due north at about 1 knot. Beyond this point there must have been a right-angle turn to the east before the Stream breaks up into the various components which find their way to Iceland, Norway, England and Spain or even back to the Stream itself by taking a loop south, the heart of which encompasses the Sargasso Sea.

depressions and holes. This type of sediment is the commonest experienced and is built up from deleterious material raining down from the phyto and zoo plankton above. The rate of deposition is extremely slow, about one inch per thousand years, but, nevertheless, the particles on their way to join the sediment can be observed through the viewing ports as tiny light scatterers when illuminated, resulting in a snowstorm effect. Even the apparently clearest of water is still full of light scatterers and has to be seen to be believed.

We saw no manganese nodules or pavement, both of which had been expected on the Blake plateau. On our excursions to the bottom in this area we observed coarse sand mixed with black sand formed into ripples of about 9 in. wavelength and 1 in. amplitude. In one area there was a very marked delineation between the sand and an area of much smaller sediment free of ripples. The sand gave an initial appearance of being very hard and compacted but fishes with a ling type appear-

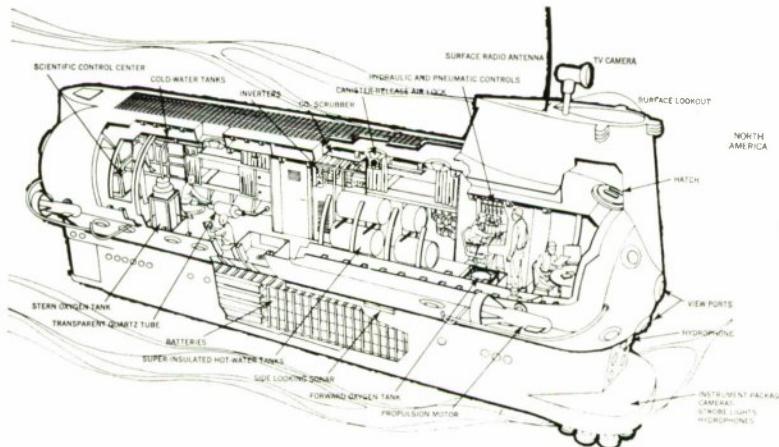


FIG. 2. General layout of
Ben Franklin.

As *Ben Franklin* drifted with the mass of water it was only when we were sat on the bottom that the current speed and direction instruments on the boat were indicative of the true water motion. This was normally implied by change of geographic position. Temperature, salinity, sound speed and water pressure were automatically measured and recorded on magnetic tape every two seconds for the complete voyage.

An excursion to the bottom of the ocean is always an exciting event even if no revolutionary discoveries are made. The very presence of being in this new world leaves you with a sense of awe. On this expedition we nowhere approached my previous diving record of 6,100 ft but, nevertheless, the awe, wonder and excitement were still there. A sea floor of pelagic sediment was the first we visited, basically flat apart from the workings of bottom living creatures who produce mounds,

ance were observed burying themselves in the bottom, tail first, with no difficulty.

The ecology of the Gulf Stream water was not as expected. I was personally mounting experiments on the deep scattering layer but nowhere did we, or either of the surface ships observe the DSL within the confines of the Stream. From the submersible I observed all the creatures usually associated with the layer with the exception of the myctophids or lantern fish: squid, copepods, euphausids and sergestes shrimp were all seen but only once were euphausids observed to be in a layer concentration. Large numbers of salps were seen, some of them living in colonies with as many as one hundred clinging together in a long "conga type" line, some very beautiful Venus Girdle and large medusae were observed, their many colours radiating in the artificial light. Common eels were seen on the fringe of the Sargasso Sea, these pre-

sumably were the American eel as the European species breeds on the eastern side of the Sea. No small or medium size mid-water fishes were seen. A school of tuna swam around us for a day at 600 ft depth; two swordfish and a shark were also observed at this depth. When we came to the surface for our tow back into the Gulf Stream we were surrounded by sharks, blues, greys and hammerheads. Marine mammals, dolphins and whales were heard every day but none were sighted from the submersible. The absence of the smaller fishes is, at present, unexplained. Unfortunately we did not have a dissolved oxygen meter on board. Most of the other environmental factors were monitored.

Penetration of sunlight into the ocean always causes interest; on this trip we could read large print at 600 ft depth. Regrettably no copy of *The Times* was available as a standard. At 1800 ft depth daylight was still discernible, whilst on one occasion the surface was seen from 300 ft depth.

Two crew members, Frank Busby from the U.S. Navy Oceanographic Office and myself were responsible for the oceanographic work. We had as much equipment packed into *Ben Franklin* as is normally carried on a surface expedition. As well as the instruments already mentioned we had a gravimeter, a magnetometer, ambient light meter, sub-bottom profiler, side scan sonar, two stereoscopic camera systems and an elaborate acoustic installation for deep scattering, volume reverberation and acoustic reflectivity measurements. Data collected by all these instruments will take several months to analyse and digest.

Don Kazimir, an employee of Grumman Aerospace Corporation, the owners of *Ben Franklin*,

was the skipper of the boat; he, along with Jacques Piccard and Erwin Aebersold, a compatriot of Piccard, were responsible for piloting. The sixth member of the crew was Chet May from the NASA Marshall Space Flight Center. Chet was using *Ben Franklin* as an analogue for a space station. This was the first time that a group of people had ever lived in a completely closed environment for such a long period. Experiments of the Sealab and Tektite type were continuously supplied from the surface with power, breathing mixtures, food, water, recreation material, medical attention, etc. We were on our own for 30 days existing on what we carried—nothing came into the boat, nothing left. Oxygen and carbondioxide were monitored continuously; checks for 30 other gases were made every day. At one time the carbon monoxide level was approaching the danger limit but fortunately the shore side experts lifted the theoretical danger limit so we were able to continue. Bacteria sampling of the crew, water and the boat was another occupation in which we all co-operated. Before the trip psychiatrists, psychologists and physiologists had been at work on the crew, documenting all their peculiarities and idiosyncrasies of body and mind. During the trip we had a daily efficiency check and a host of questions to answer. On our return we were subjected again to further tests.

Since returning I have been asked a number of times if I would go again, and could we have stayed longer. I believe that much longer periods than 30 days are possible, if you are motivated. At no time was I bored. There was always something new to be learned. The oceans still have a lot to reveal to us. Yes, I would go again.



FURTHER PROBLEMS ON THE DEVELOPMENT AND APPLICATION OF EFFECTIVE ANTI-CORROSION PAINT SYSTEMS

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Abstract

The main problems experienced with anti-corrosive paint systems can be said to fall into two main categories. Those met in the development of new or modified materials and those mostly concerned with the attainment of satisfactory application conditions for these materials.

The development of materials is largely a slow, evolutionary process of improving existing coatings. Occasionally we have the emergence of a fundamentally new film-forming material which is suitable for use in the development of new paints.

Progress must therefore be maintained in both the material and application fields.

The main problems currently being faced appear to be in the application field where the acceptance and planned use of the new preparation and application techniques available would allow better results to be obtained from the materials specified.

In this paper the whole field of ship painting is discussed under the following main headings and an indication given of possible solutions to the problems being faced under each heading.

- I Outer Bottom Paint Systems
- II Weatherwork Paint Systems
- III Interior Paints
- IV General

The painting of ships still presents some of the most difficult problems that are met with in industrial coating work. The painter is, faced with large areas of steelwork, usually in unsuitable atmospheric and climatic conditions, and with materials whose recommended procedures for application appear to be more suitable to a laboratory than the bottom of a dock in the pouring rain. The demand for improved performance can be met by better application of existing materials and by use of new improved materials. This in turn must lead to higher standards of preparation and application. The "perfect" material to meet all requirements, that is one which can always be applied satisfactorily under the most adverse conditions, is as yet, unobtainable. Until it is found, it is inevitable that we will be faced with innumerable problems on the development and application of materials to give more effective anti-corrosive paint systems.

For the purpose of this review, consideration is given to outer bottom paint systems, weatherwork paint systems and interior paint systems and the problems that the MOD(N) are currently considering as a result of Fleet experience with the materials concerned.

Outer Bottom Paint Systems

(a) Coal tar epoxy system

Ships fitted with an impressed system of cathodic protection are specified to have the outer bottom coated with a coal tar epoxy system giving 0·009 inch over peaks in three coats.

For new construction there have been few problems with the introduction of this material, although some concern was expressed at the possibility of the CTE coatings not curing adequately in the lower temperatures met in the U.K. winters.

This has not been observed in practice where cure has subsequently been completed and good results obtained.

When coal tar epoxy is used on new construction it is inevitable that it is applied over residual prefabrication or shop primers. It is therefore important that the primer and CTE be considered as a system as regards adhesion and performance under cathodic protection conditions, to ensure that the protection required is achieved and the full performance of the CTE attained.

In the commercial field it is known that there is considerable evidence of corrosion and pitting of the steel substrate and stripping of CTE systems after periods of 18 months or so in service. The main differences between naval and commercial practice appear to be:—

- (1) CTE in R.N. ships is used in conjunction with full cathodic protection—in commercial ships this is not always the case.
- (2) MOD(N) specifies a three coat system of CTE—commercial hulls are more often than not coated with a one coat high build CTE.
- (3) R.N. ships are maintained at each docking by an overall tie coat of aluminium bitumen (anti-corrosive coating) prior to the application of the anti-fouling overall—normally, commercial hulls apply anti-fouling on certain specified areas of the wall sides only.

There has been, as yet, no evidence in R.N. ships of the type of corrosion and pitting observed in commercial shipping, and any stripping has been confined to maintenance systems of aluminium bitumen and anti-fouling, and not to the basic CTE.

It is considered that the good results obtained in the R.N. ships are attributable to the fact that a multi-coat system of coal tar epoxy is used in conjunction with a full cathodic protection system.

For general maintenance of ships in for refit and recoating, etc., problems are met with the application of a coal tar epoxy system to hulls which are freshly abrasive blasted. Successive coats of CTE must be applied within seven days. The current method used in dockyards for abrasive

blasting ships' outer bottoms is by vacu blast equipment; this by nature is a slow process preparing the steel surface at some one tenth of the rate that it takes to apply one coat of CTE by brush. The steel which has been abrasive blasted at this slow rate, must be coated within four hours and subsequently overcoated within seven days. This presents problems in planning of the work, even when application is by brush or roller. The introduction of airless spraying techniques with their even faster application rates, which lead to overall advantages and economics in man power etc., still further aggravates this planning problem.

Improved and faster means for preparation by abrasive blasting are under investigation, but considerable advantages would be gained in the seven days' time limitation between successive coats could be extended. This is being investigated.

(b) ACC 655 systems

The standard outer bottom anti-corrosive coating for R.N. ships which are not fitted with the impressed current CP system is ACC 655 an oleo-resinous material pigmented with aluminium, basic lead sulphate, iron oxide etc. On new steel ACC 655 gives a smooth coating with good protection against corrosion, but recent experience indicates that considerable care needs to be taken to ensure an adequate coating thickness, particularly when being applied over freshly blasted steel. When applied by brush or roller it tends to give thin films and in several instances it has been found necessary to apply eight coats instead of the normal five on steel that has been freshly blasted in order to give the required thickness of protective film over the peaks. The profile of abrasive blasted O.B. plates must not exceed 0·003 inch and normally lies between 0·002 inch and 0·003 inch.

When applying ACC 655 by airless spray techniques it is necessary to limit each coat applied to 0·004 inch wet film thickness. If this is exceeded, slow through drying and surface wrinkling can take place which in conjunction with solvent retention in the films, can give rise to poor finish and inadequate intercoat adhesion.

Work is in hand for a high viscosity version of ACC 655 to overcome these application problems and enable thicker films to be applied by brush or roller. It is not anticipated that significantly thicker films can be applied by airless spray.

Whilst superior on clean steel, ACC 655 is unsuitable for use as a touch-up material on old coatings of anti-corrosive and residual anti-fouling. Stripping usually occurs when ACC 655 is used in this way, due to the fact that it is water resistant and relatively impermeable to absorbed water in the old coatings. This, in conjunction

with the difficulties in 'wetting' old porous A/F surfaces, leads to the applied film being pushed off in time. Admar, which is used as the tie-coat on ACC 655 prior to the application of the anti-fouling, is used as the touch-up paint on ACC 655.

(c) *Waterline protection*

The basic painting schemes above are currently specified for the waterlines of H.M. Ships. Whilst they give reasonable protection they fall well short of desired performances in resistance to abrasion which is a particular problem in the midships areas.

Over the years a large number of anti-corrosive coatings have been put under trial to assess their resistance to abrasion under ship service conditions. The materials have included chlorinated rubber, solvent free epoxies, cementiferous types, as well as zinc dust alkali silicates. In all cases these materials have required frequent renewal on freshly blasted surfaces which leads to application problems which largely outweigh any minor improvements obtained in overall performance. Zinc dust alkali silicates show some promise however, and trials of this type are still proceeding.

The adoption of zinc dust alkali silicate materials would give rise to further application problems which would require detailed consideration. Experience to date shows that each type of zinc silicate material requires a different set of application conditions if the optimum performance is to be achieved.

(d) *Rudders, shaft brackets, sea inlets, etc.*

The availability of a coating for rudders and shaft brackets which gives satisfactory protection over at least the period between refits as a minimum, is still under investigation by ship trials. For these items, materials to the 'Araldite' formulation 'X83/44'—a solvent free epoxy material—are still specified. To date this material has given the best results but the performance is still not up to the standard required, particularly on the leading edges of rudders. Many of the breakdowns of the Araldite materials under the extreme conditions of cavitation and high water flow etc., are considered to be due to the application characteristics of the materials themselves. To an extent these vary between different manufacturers, but by far the dominating factors are the varying conditions under which the materials have to be applied. No pattern of failures can be traced which can lead to a direct proposal for improvement. The paint industry is assisting in the development of materials which have, at least, the performance characteristics of the Araldite formulation, but are more tolerant of the conditions under which they have to be applied.

As Araldite material to X83/44 formulation is the best available so far, attempts have been made to re-inforce it with glass fibre cloth. Where convenient, the structure is being 'bandaged' during application of the solvent free epoxy material. Where continuous bandaging is not possible, sheets of glass cloth are being rolled into the Araldite during application.

The same epoxy material has been successful as a coating for sea water inlets and discharges where the correct standard of preparation can be achieved. Failure rate of sea tubes, however, remains unacceptably high which points to the difficulties in obtaining the preparation standard so necessary for application of this type of material.

The tendency to smaller sea tubes is increasing the problems in abrasive blasting to achieve the standards of preparation, and in many instances the proud weld runs at the tops of sea tubes are causing early breakdown of the epoxy coating leading to more general failure. The fitting of zincs is mandatory for all sea tubes which can be blasted and coated with epoxy Araldite coating, but the improvement of the performance of the tube coatings by better preparation is imperative.

(e) *General application*

A new technique for paint application can seldom be introduced without it having some effect on, or being affected by, other procedures which are normally carried out on the outer bottom at the same time. This is of particular importance for outer bottom painting where the schedule of work for a ship in dock is normally very tight. The introduction of newer techniques for preparation and coating the outer bottoms requires a thorough re-appraisal of all the practical problems involved. Only when the preparation and painting are accepted as being items of major importance and receive suitable priority in planning and scheduling will it be possible to meet the demands for improved performances and achieve the manpower and economic advantages offered by the better techniques.

Weatherwork Paint Systems

(a) *Hull painting*

Trials have been carried out on three frigates to assess the practicability of achieving a *Britannia* finish with minimum of maintenance. The hulls and superstructures have been cleaned back to bare metal and coated with a full system of three coats of primer, one undercoat and one or two topcoats. Fairing of hull imperfections has also been carried out using rivet filler, and special attention has been paid to removal, or cleaning and coating, of rust raisers *i.e.* those areas giving

rise to premature breakdown and subsequent rust staining of other paintwork.

On each ship a comparison was made between the standard MOD(N) specification paint systems and a selected proprietary marine weatherwork system.

The first phase (two years) of these trials is now complete. Some interesting facts have emerged:

- (1) There is no reason to depart from the use of the MOD(N) specification weatherwork paint system. It is at least as good as, and in most cases better than, the commercial paints with which it was compared.
- (2) Repainting overall of the hull can be reduced from about every two-and-a-half months to about every nine months.
- (3) Appearance can be maintained to an acceptable standard by regular washing of paintwork; this enables better attention to be paid to immediate touching up of paint films where mechanically damaged.
- (4) The improved appearance overall can be achieved by reduced manpower effort.

The trials, however, have brought to light certain deficiencies which need to be made good to ease the maintenance problems associated with weatherwork systems.

The non-setting red lead used as the basic primer in MOD(N) work, whilst satisfactory for use in dockyards where the long drying characteristic is acceptable, is not suitable as a primer for general maintenance and repair afloat of damaged paint work. In such cases the time available is usually short and this demands a first aid touch-up primer which can be applied to give the required anti-corrosive protection and be subsequently over-coated after overnight drying. Red lead graphite will go part way to meet this, but there remains the requirement for a primer which will give the equivalent thickness and protection of three coats of red lead within the 24-hour, overnight drying period. Consideration is being given to achieving this by a *very* quick drying material of conventional thickness or the use of a high build material. Materials which give this thickness are necessary to fill in the damaged areas and so restore a fair surface to allow local touch-ups to blend in with the surrounding areas.

The availability and use of such first aid primers is essential if the long life performance of which weatherwork finishing paints are capable, is to be achieved in service.

The high gloss and colour retention properties of the MOD(N) specification weatherwork paint are such that an acceptable appearance can be

maintained for at least nine months by careful washing and touching up. In one trial ship 12 months and 13 months were achieved between overall repaints. The paint coatings after these times were in a remarkably good condition and fully protecting the hull. The touch-up repairs to the hull paint work became rather obvious in the last three months or so, when examined close to, and the overall appearance at this stage was considered to be below the normal RN standards.

The success achieved as regards appearance was due to immediate repair of damaged paint films and regular and frequent washing down of paintwork to remove salt, dirt, etc., to prevent it becoming ingrained in the paint surface. A more effective means for thorough washing and cleaning of paintwork is required. Apart from removing the salt, dirt, etc., any washing process must not do permanent damage to the paint film and not impair its colour and gloss. Paint surfaces treated in this way must remain in a satisfactory condition for overall painting when this is considered necessary.

The key to a satisfactory long-life weatherwork paint system is in the basic preparation, priming and initial painting. This can only be met by carrying out the work in shipyards or dockyards using skilled painting labour. A high standard of maintenance by ships staff, however, is of equal importance and it becomes essential to ensure that the maintenance routines and repair of damaged areas are carried out to the best possible standard with the materials available and under the conditions prevailing.

The weatherwork paint trials included the application of two gloss topcoats over the one undercoat as well as one gloss topcoat on one undercoat. Sufficient evidence has not been obtained to warrant the additional topcoat and further investigations are required on this.

Practical problems are bound to arise if and when the additional topcoat is specified. It will call for three coats of weatherwork paint to be applied after preparation and priming of damaged areas. In the time scale that has to be worked to by ship's staff for maintenance this is at present unacceptable. It is possible that the requirement could be accommodated if a comparable saving could be made in the time required to give full anti-corrosive protection in priming.

For maintenance and overall painting by ships' staff a single coat weatherwork paint remains a firm long term requirement. This means a paint with all the desirable topcoat properties, colour, gloss, etc., and which can be used initially with or without an undercoat and subsequently over-painted by a single coat of itself. It would be very difficult for a single coat of paint to match the

present performance of the standard weatherwork paint system in retaining its properties within acceptable limits for 12 months or so.

The remarks above have been made mainly in connection with painting, maintenance and repainting of the hulls above water. The trials also showed that the performances of the paints on the superstructure and upper works were broadly similar, and in many cases could be left considerably in excess of 12 months without an unsatisfactory deterioration in either performance or appearance. These areas are, of course, subject to less severe physical damage and the conditions of exposure give a lower order of breakdown.

It is of note that the structural paint film breakdowns, where occurring, were worst on the hulls near the waterlines. The degree of breakdown became progressively less up the ship-side away from the waterline.

(b) Weatherdecks

The preservation and the satisfactory appearance of weatherdecks generally has always been a problem in R.N. ships. The requirements for appearance and slip resistance properties, together with ease of maintenance have conflicted, to some extent, with the anti-corrosive and preservation requirements. Inevitably, improved systems demand higher standards of deck preparation or improved preparation techniques. Difficulty is found in injecting these requirements into building or refitting schedules without affecting the progress of other work, or even the overall programme. This is a major problem and is currently under active consideration.

The problem of maintaining an acceptable standard of preservation with the current deck paint systems used in the R.N. has led to the MOD(N) adopting the RAN system of metal spraying all weatherdecks prior to the application of a deck paint. After abrasive blasting one coat of sprayed zinc is laid to a 0'001"-0'002" thickness followed by sprayed aluminium to give an overall metal coating thickness of 0'006". The painting system now being adopted by the MOD(N) to seal this surface is a two coat system of deck green epoxy paint. From trials on steel decks this material has been proved to be a satisfactory deck paint with good wear resistant properties giving long life and reduced maintenance demands.

The final non-skid finish is obtained by the use of abrasive tread strips stuck on to the paint coating. Consideration is being given to introducing some non-slip properties into the final epoxy topcoat. How successful this can be without the other properties of the paint being affected has yet to be established.

Successful trials have been carried out on ships where the officers and men have been provided with non-skid footwear and the non-slip deck paint dispensed with in favour of the standard gloss deck paint. This is being investigated further.

While improvements to the deck system now being adopted may still be possible, the main problem yet to be solved is the planning into ships' fitting out and re-fitting programmes, of the necessary time and conditions to enable the standards of abrasive blasting required for metal spraying and subsequent painting to be achieved.

A further major problem which the MOD(N) has faced, has been in the provision of an anti-corrosive coating for helicopter landing platforms. Originally the deck coatings used on the parking areas of RN aircraft carriers were specified for helicopter landing platforms in frigates *etc.* The heavy traffic and wear on these decks and possibly the flexible and uneven nature of these thin deck plates soon brought to light the inadequacy of the non-skid paint system to prevent corrosion. A new red lead epoxy primer has been developed, for use with the proprietary non-skid paint and in lieu of the original proprietary primer. This has eliminated the corrosion spotting problems. The red lead epoxy primer CDL225/66 is now specified as the primer for the non-skid paint EC1490X, and is being introduced as helicopter platforms need to be abrasive blasted for re-coating. The superior performance of the priming coat has enhanced the life performance of the non-skid topcoat. As a result, repeated applications of the topcoat on old topcoat has enabled a satisfactory standard of deck finish to be maintained without frequent re-blasting for renewal of the whole system.

While the introduction of the red lead primer has resulted in a decrease in the general maintenance problem of non-skid systems as far as ships' staffs are concerned, there remains a need for a non-skid finish which will keep its properties longer under service conditions than the current material in use. Materials submitted by firms to a test schedule prepared by DG Ships/CDL are currently under review.

Interior Paints

(a) Bilge paints

A major problem still remaining is the adequate protection and maintenance of bilges in R.N. ships. The introduction of abrasive blasting and metal spraying in new construction has contributed in a major degree towards general preservation. Inevitably, areas of zinc spray are damaged during building and fitting out. Particular attention needs to be paid to these areas as, if they are not adequately treated at this stage, they remain

potential sources of premature breakdown which could well affect the whole preservative system.

There remains the need to treat bilges which have not been, and which are unlikely to be, blasted and metal sprayed, and to provide a satisfactory paint system which can be maintained by ships' staff.

The conditions prevailing in bilges, particularly machinery space bilges, do not allow adequate cleaning and preparation to the required standard at periods other than ship refits. Even then, the need to meet machinery commitments normally precludes sufficient time being made available to clean and prepare the structure to the standards required. This particular problem has still to be faced squarely by refit planners. Provided the condition of the bilges can be brought to a standard to accept the paint materials available for use, it is possible to achieve a considerable improvement in the standards of preservation with the advantage that maintenance between refits can be reduced to the absolute minimum. Investigations are already well in hand to assess the effects on structure of not painting bilges between refits. This investigation is based upon the bilges being carefully prepared and painted at a refit, and accepts the natural deterioration of the preservative paint coatings between refits. From the preliminary findings to date it would appear that, provided the initial preparation and painting has been carried out properly, any structural deterioration in service is likely to be within acceptable limits.

The degree of additional protection obtained from re-painting bilges between refits when adequate preparation cannot be achieved, is not considered to warrant the man power effort which must be expended by ships' staff.

Allied to the problem of re-painting bilges at refits is the suitability of the bilge paints themselves for overcoating after contamination from bilge water and oil. Improvements in cleaning and preparation are continually under investigation, as are searches for materials where protection, performance and appearance are at least up to the current standards and which are rather more tolerant of standards of surface preparation for overpainting.

The search is made more difficult since white finishes are preferred. Recent work shows that aluminium pigmented materials may well give an enhanced performance and reduce the problems in recoating. Other materials are also being considered for use in bilges and the whole question of standard and colour of finish may need to be re-considered.

(b) *Tank coatings*

There is an increasing demand for tank coatings which not only protect the structure from corrosion attack but also protect the fluids contained from contamination. For most of the demands dealt with to date there are materials which can satisfy both these requirements, but once again, the need for correct surface preparation and possibly subsequent treatment or curing of the material becomes of paramount importance. Where the tanks are large, the practical problems that are met in abrasive blasting and coating etc., should be able to be solved by careful planning of the work involved. In small tanks, however, the problems are becoming acute. Access for blasting equipment and personnel is restricted and as the standard of preparation is normally dependent on ease of access, the required standard is more often than not impossible to attain.

Where cleanliness of fluid carried in a tank is of vital importance and where corrosion products from the structure may contaminate the fluid, sound continuous coatings free, from imperfections in preparation are essential. The normal tank structural arrangements in ships are such that internal framing and stiffening, etc., make the required surface preparation impossible to achieve over the whole complex surface. In such cases, consideration should be given to the structural design of the tank itself. Where possible, the removal of the internal obstructions to facilitate the detailed preparation and coating requirements needs to be given priority.

Generally, improvements still need to be made where all high duty coatings are being applied. Apart from the surface preparation of plates etc., the grinding of welds, edges to sections, cut edges etc., need very careful attention and preparation if premature breakdown of the coatings is to be avoided; otherwise the economic advantages of using such coatings are largely lost.

The application problems of such coatings also need continuous consideration particularly as regards ventilation and adequate curing temperatures. This is again of vital importance in the smaller tanks where access is difficult and where adequate venting of structural pockets and corners difficult of access needs special care. If this is not achieved, hazards can arise from retained solvents and this, together with incomplete curing could lead to serious coating failures.

For aviation fuel tanks, a solvent based epoxy material cured with amine adduct or polyamide has been found to give good results, including long term performance, provided the required standard of preparation of difficult areas e.g. welds, cut edges etc., can be achieved. It is

intended to adopt this material as the standard for all types of fuel tanks in R.N. ships.

(c) *Fire retardant paints*

Problems still remain regarding the suitability of the interior paints used in R.N. ships for meeting the standards required in resisting burning and in retarding the spread of fire. This property has to be considered in conjunction with the requirements for gloss, colour retention, etc., in order to provide an acceptable decorative finish. Until now, the current MOD(N) philosophy has been to use paints whose major fire retardance qualities were in preventing spread of fire from adjacent compartments. To this end, the fire retardance test for these materials has been designed to assess the ability of the paint to resist a selected rate of heat rise from the other side of a steel plate; the nature of the deterioration of the paint film itself under this heat and the combustion of the products evolved are also considered. It has further been policy to resist the use of halogenated compounds such as chlorinated rubber, in considering new paints that will give improved fire retardant properties whilst maintaining the required standards of colour, gloss, opacity etc.

The current materials in use tend to lose their fire retardant qualities as they age, and in addition, the thick coatings which are built up over a period of service probably possess little fire retardant property although the individual paints when tested meet the specification requirements.

Investigations carried out to date have given a number of possible leads towards a solution but other problems such as solvent retention and application difficulties arise. Two basic problems remain. Whether the present approach to fire retardance testing is the correct one; if so, the degree of realism in the test needs to be re-examined. Secondly, whether chlorine bearing materials can be accepted and the type of solvents that should be used in such materials; the possible relaxation of the gloss requirements and the acceptance of an "eggshell" finish may need to be considered here.

The whole question of the fire hazards from materials used in R.N. ships is currently under review. Each material used is now being considered as regards its potential fire risk and the degree of risk is being quantified together with the types and quantities of smoke and gases evolved in a fire. The risks from interior paint coatings will be considered in relation to the other materials and further research and development work into a fire retardant paint will not commence until an agreed standard of acceptance can be finalised.

General

Painting in R.N. ships has a dual purpose—maintaining preservation and keeping up appearances. By far the majority of painting carried out in ships has to serve both aspects of this dual rôle of preserving the structure beneath, while presenting an appearance which is attractive and at the same time easy to keep clean. Both these requirements are important, but long term appearance to the standards required will not be obtained and maintained unless the requirement for sound basic preservation has been satisfied first. Unfortunately, the correct balance of priorities is often overlooked under the pressure of an immediate need to keep up an appearance.

As throughout the whole of the user/painting field, the carrying out of preparation work prior to painting is often subordinated to the rather more satisfying application of paint where the progress is immediately apparent.

The appreciation of preservation of structure as a fundamental requirement in ship maintenance remains a prime requirement. With the lighter scantlings used in ship construction and the more sensitive materials which have to be used to meet the advanced tasks or longer performances required, it is clear that more attention will have to be given both directly and indirectly to the needs of painting during both ship refits and maintenance periods.

Another factor which can have important repercussions in obtaining the best results from our present schemes is the continuing reduction in quality of labour which is available for preparation and applying the materials. It is unfortunately a common fallacy that "anyone can paint" and further that anyone who has done some house painting is an "expert" in all fields! While we are still searching for the "perfect" material referred to earlier in this paper, this constant erosion of the quality of labour available is in direct opposition to the increase in standards of surface preparation and application necessary for the use of the modern high duty coatings. Unless this is recognised and attempts made to change it by accepting the importance of painting as a basic preservation process, and developing facilities, processes, training, etc., accordingly, it will be difficult to ensure that the standards of performance of coatings currently in use are maintained. The performance of even further improved materials, perhaps requiring more sophisticated preparation or application routines, may well be doomed to premature failure.

Looking to the immediate future we can foresee problems with painting and subsequent maintenance of the newer synthetic materials being introduced into Service.

Particular problems will arise with the preservation painting of glass reinforced plastic structures to maintain the standard of appearance normally accepted by the R.N. Additionally, for these materials there will be the problems of removal of paint films without damage to the underlying structure and then further re-painting.

In recent years much more attention has been paid to the safety and health hazards in applying materials generally. This trend seems likely to continue and, together with the impending change

in flash point regulations as far as paints are concerned, may well introduce considerable problems. Consideration will need to be given to possible changes in formulation of current paints which are giving satisfactory performance in service.

Acknowledgement

This paper is published by permission of the Ministry of Defence (Navy Department) but the views expressed are personal to the authors.



PHYSICS EXHIBITION 1970

The 54th Physics Exhibition will be held at Alexandra Palace from 2nd - 5th March, 1970, and as on previous occasions the Ministry of Defence (Navy Department) is participating.

The development of the Moiré fringe technique to ascertain strains developed by welding is being shown by the Naval Construction Research Establishment. The Naval Ordnance Inspection Metallurgical Unit is demonstrating a non-destructive testing method for the measurement of the depth of hardened layers. The Services Electronics Research Laboratory will be showing a new heat sink technology for microwave avalanche generators, also a prototype high power argon ion laser of compact design, using beryllia to confine the discharge, and finally a demonstration of high resolution holography.

AUDIO VISUAL TRAINING METHODS IN USE IN H.M.S. VERNON*

Instructor Lieutenant Commander C. W. Dunnett, B.Sc., M.I.T.O., R.N.
H.M.S. Vernon

It has always been a desire to develop a simple matrix system by which a programme for AVIT or Dia Pilot could be easily and logically produced. The results of such logically developed processes, taking the individuality out of a presentation, is a worthy aim in a rapid turnover training situation such as we have.

In order to understand what I have done in H.M.S. Vernon, it is necessary to explain in more detail the method of working. Conclusions will be drawn as I progress and a programme of events for a production line will emerge.

If one can treat the lesson on the machine as the goods, they must first be sold to the buyer—this is of course before they are even produced. By sold, I mean to persuade the buyer that he needs them. Having performed this basic requirement the Behavioural Analysts must get to work and mould the order into terms acceptable to the programmers. Such 'woolly' requirements as 'to have a basic knowledge of', need correcting into the true behavioural term of 'to be able to recognize' or 'to be able to state' or 'to be able to take to pieces' etc. in the exact terms that the buyer really needs. The behavioural analysis is more fully described in the method and terminology of Mager⁽¹⁾.

Whilst this process of selling the programme is going on I have developed a situation whereby the existing lesson plan is cleaned up and presented in script form correlating frames in proposed pictures, book and audio ideas, in fact, a completely integrated programme. The decision of picture or

audio in some cases, being the only subjective decision in the whole process.

The programmes can then be spoken of as programmed, as well as being completely integrated in their audio and visual aspects. Each audio instruction and visual frame of presentation is regarded as an integrated 'frame' complimentary to each other and it is due to this 'science' of programme construction that leads me to call this method of presentation 'systematical'. To avoid any confusion with the device, this is a System's approach to Programme Writing itself.

The immediate savings, benefits, call them what you will, are:

- (1) The ease with which any topic can be changed or modified.
- (2) Any staff requirement can be introduced or confined.
- (3) The quality control of all lessons programmed.
- (4) The expert instructor not being familiar with the particular syllabus or 'depth' of approach can use the system immediately.
- (5) The non-availability of the specialist instructor becomes unimportant.
- (6) The existing traditional advantages of Programmed Learning, and,
- (7) All the material can be 'home-made'.

With these advantages in mind and particularly Item 7, let us proceed to the actual task of constructing a programme. This must be, strictly according to the network schedule shown in Fig. 11 which is similar to many other such procedural analyses. One specific difference is that it is a

* See also J.R.N.S.S., 24, 6 (November 1969), 311 for initial article.

DEVELOPMENT OF SOFTWARE

requirements of the ordering department. Suffice to say that after a long discussion and investigation the objectives were written by myself as:

1. To recognise the torpedoes in Service by their exterior appearance and colour, from photographs and finally from actual examples.
2. To be able to state the means of delivery of all the torpedoes and the form of guidance, if any, which they use.

This was now in a form suitable for any programmer to apply his art, but first back to the Schedule, where it can be seen that a validation or criterion test based on these objectives must be produced. Clearly the test must take the form of a set of photographs and short multi-answer ques-

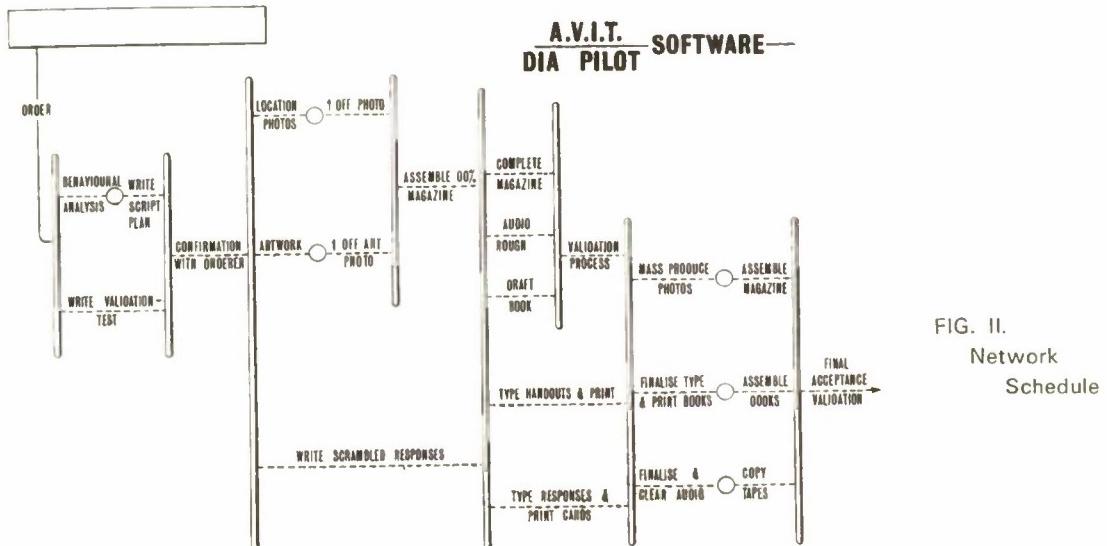


FIG. II.
Network
Schedule

path network to construct something which has had to be used as soon as possible, and the reformulation of objectives, in the light of what has been proved to be incorrect, cannot take place, they must be correct first time. A new frame, or a new explanation, must be produced to satisfy the original objective as accepted and finally stated and not, as many programmes have done in the past, taking the objectives to be absurdly simple for the sake of achieving them.

The initial 'order' for a programme from the user field will consist inevitably, as was said earlier, of rather 'woolly' subjective terms, and the first task, as in all programme writing, is to clarify these into objective terms. A typical such 'order' I recently received was to construct a programme that would replace a lecture in current use called, 'Torpedoes in Service'. This could mean many things, not the least of which was the actual detail

tions. It is necessary in this case not only to test—'What torpedo is this?' but also the inverse question of 'how many blades has the propeller of such and such . . . ?' These inverse questions in the validation test help to establish the true gain of 'knowledge' by the student and tend to remove the guesswork element of one way response frames.

The Validation Test is now ready to be represented to the ordering department for their final approval and confirmation of the fact that it was what they required the student to do at the end of the particular unit of instruction. Once this is established we are then on our own to reach our objective, that is to construct a programme which will satisfy the ordering department's objective.

To ensure that all facts and figures are included, it is now necessary to construct a matrix of the form overleaf:

	Torpedo 1	Torpedo 2	etc....
Size Colour Shape etc.			
In multiples	Comparatives		
Delivery			
Guidance			

This will in fact have developed very easily. At this point each item in this matrix must be included somewhere in the programme whereby all the necessary facts will be covered. The Matrix is the master plan, *NOT* the programme plan which is now considered.

The programme plan can be formulated by simply breaking the original lesson plan down into audio-visual frames with factual statements. These statements by reference to the Matrix or even by a tick off procedure will give a precise coverage of everything that is required. An example of a lesson plan with the relevant audio visual skeleton is depicted in Figs. 12a, b.

Previous knowledge	None.	NOTES
1. <i>The need for minehunting</i>	(a) To clear unsweepable mines. (b) To expedite clearance of mines fitted with high ship counts and arming delays. (c) To clear mines in areas inaccessible to minesweepers. (d) To gather intelligence of mine circuits by recovery of mines for investigation.	Part 1

FIG. 12a. Lesson Plan.

Perhaps at this stage one should emphasise again and not be so glib as to assume complete objective systemisation in the division and choice of what 'to picture' as opposed to 'speak about on tape'. This decision is clearly subjective, even though the integration of audio and picture must be objective, i.e. one man's choice of picture and words will differ from another but the swings and roundabouts of such a semantic argument will only delay production and not show any fruits of efficiency worthwhile, other than in retrospect, and

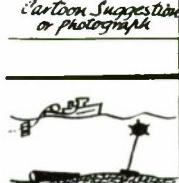
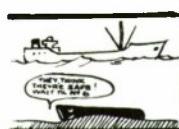
(COPY OF ORIGINAL) <u>Minehunting System Acoustic Mk.1</u> <u>Sonar Type 193</u>		Facts
Cartoon Suggestion or photograph	Topic / Audio Book	
	<i>The need for Minehunting.</i> Can't be swept because:- unarmed, no Sweep available, economy. So we devised a method of finding the mine first.	① Unarmed ② No Sweep available ③ Economy
	<i>Difficult Mines.</i> Period Delay - Complex circuit - High Ship Count - Summarise the requirements that prompted 193 ie difficult mines that we had to find first.	① Unarmed due to delay mechanism ② High Ship Count ③ Complex circuit
	<i>Intelligence</i> Minehunting because we can recover mines & hence investigate circuits and settings	① Recovery for investigation
	<i>Card Response required</i>	

FIG. 12b. Visual skeleton.

that only after validation. With this type of equipment as a presentation device it is comparatively easy to change the picture, or the words, when they are proven inadequate. Again, as soon as we move away from objective decisions, time is wasted and arguments as to effectiveness ensue.

On completion of the Matrix, and picture choice, the photographer and artist or illustrator can get to work. It is interesting to note that at this stage in my own unit at H.M.S. *Vernon* we are progressing five programmes simultaneously and it is only possible to keep track of each by use of a rigid network schedule such as is shown in Fig. 11.

With artwork and photography almost complete, a magazine of slides can be constructed in a sequence to match the lesson plan. Then, using only the topic heading in the audio/visual skeleton, I make an 'off the cuff' tape recorded commentary. This has proved to be of great benefit in deciding the language style of presentation, by immediately, without the expertise of a script-writer, giving a commentary and not prose. Finally, by longhand scripting, the tape can be cleaned of grammatical howlers, corrected, and generally made more presentable.

The programme, with a commentary, is now at a stage where a response analysis can take place. The object of this analysis is to ensure that each

and every behavioural objective is included with a response and by a simple check off list, which again is the Matrix itself, the primary objectives are spread evenly throughout the programme with such responses. These can include corrective measures in a form of branching included in the multi-choice questions. The questions and answers are made up in card form in a loose leaf book as is illustrated in Fig. 13a, the method of printing.

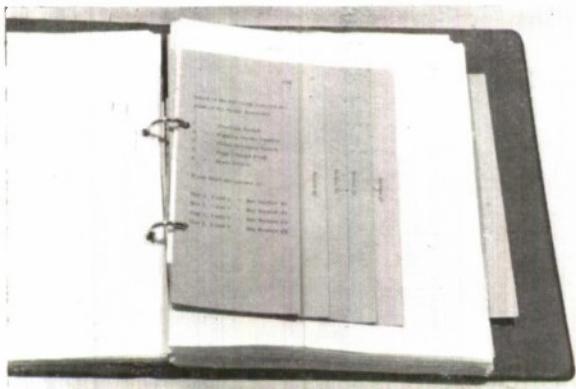


FIG. 13a. Typical page from book.

purely to save printing costs, is by assembling the cards into standard sizes which require cutting up afterwards. A card before cutting is shown in Fig. 13b.

At this stage a few words on printing is worthwhile. It is my confirmed belief that the more 'professional' the written work the more acceptable it is to the student. Artwork done quickly will only spoil the whole effect. Handwritten Gestetner skins are more expensive than a typed Multilith, or other such paper Litho master plate. The result of printing by Litho is infinitely more acceptable. This argument is just as valid with the 35 mm transparencies used on the actual cassetted programme magazine. Colour film is more costly but its impact and effect is 100% better than black and white.

<p>Which of the following descriptions of Sonar Sets best fits the Sonar Type 193 ?</p> <p>(a) A long range attack sonar. (b) A medium range high frequency sonar. (c) A close range high definition sonar. (d) A close range attack sonar. (e) A passive sonar.</p> <p>Open the section you think is the correct answer . . .</p>	<p>(12)</p> <p>No. This is the wrong answer.</p> <p>A passive sonar is one which cannot transmit and can only receive signals; that is, it only listens.</p> <p>Section (e)</p> <p>Turn back to the question and try again.</p>
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FIG. 13b. Card before cutting.

The Objective Analysis throughout has resulted in many 'close looks' and changes in doctrine, by ordering departments as a direct result of the systematic approach.

I have concentrated on the development of an AVIT programme, as it must be considered to have the edge on the Dia Pilot for most subjects. Despite this, Dia Pilot lessons are of great value and are produced in an identical manner. The responses can be achieved with a book of scrambled responses for each pupil in a Dia Pilot Class. The Instructor controlling the progress of the tape for the whole class instead of the pupil controlling his own progress, as on AVIT.

Dia Pilot lessons are chosen and considered as more efficient than AVIT in some specialised topics, particularly those topics where an instructor's experience is likely to be called upon. Objective frame writing can answer and train to all the objectives but there remains the enquiring mind of the pupil to whom the answer of a question from a real situation becomes a personal point of information, and however unimportant to the system, important to him as an individual.

These specialised topics are usually at the beginning of a course and the objective is really reformed to be that of motivation where the Dia

Pilot has the additional advantages of the live instructor.

May I finally add that this presentation device has been developed in parallel with a method for using it. I believe it to be simple in operation, relatively quick to apply, and cost effective. The material presented can only be improved, or amended as situations change, thereby never being affected by new staff members, or new brooms, which all too frequently sweep aside an existing system for the sake of exercising the broom handles on a spotless deck. The home-made nature of the software (despite my remarks above—the system will work with handwritten frames and your own 35 mm camera results) make this whole system a viable and valuable aid to Modern Education and Training.

Acknowledgements

The Instructor Officers, H.M.S. *Vernon*, who helped in the production of this article. The Technical Illustrators' Pool and the Photographic Section of H.M.S. *Vernon* for the drawings and photographs.

Reference

- ⁽¹⁾ Mager, R. F., "Preparing Instructional Objectives" (Fearon 1962).



TRACE ELEMENT DETERMINATION BY NEUTRON ACTIVATION ANALYSIS

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Introduction

Increasing quantities of radioactive effluent are being deposited into the coastal waters of this country as waste from nuclear installations. The risk to man from this disposed radioactive material can be distinguished as a twofold problem involving (i) external and (ii) internal radiation hazards. External problems arise from this dispersed radioactive material becoming transferred by settlement or adsorption, into some surface with which man comes into contact, such as a beach or fishing equipment. The internal hazard arises primarily from man's consumption of contaminated food through marine food chains, as a consequence of the ability of aquatic organisms to selectively concentrate certain chemical elements to a very high degree.

The criterion underlying the estimates and subsequent control of the rate of discharge of liquid radioactive wastes is simple but very demanding; namely, that no single member of the public, as a result of such discharges, shall be required to change his habits and tastes, or be deprived of the natural amenities and enjoyments to which he is accustomed. Expressed in more practical terms this means that no member of the public should receive more than one tenth of the level of radiation recommended by the International Commission on Radiological Protection⁽¹⁾ as permissible for occupationally exposed persons.

This criterion has provided a basis for the amount of liquid effluent which it is permitted to dispose to coastal waters and Table I lists the exposure factors involved in the discharge of aqueous radioactive wastes from establishments in the United Kingdom⁽²⁾. In each of the cases listed

the maximum permissible rates of discharge of active effluent have been greatly influenced by human consumption of contaminated marine plants and animals in the environment.

A parameter of fundamental importance in practical assessments of permitted rates of discharge is the 'concentration factor' defined as the ratio of the mass of element per unit mass of organism, divided by the mass of element per unit mass of sea water. This ratio applied to the uptake of zinc in oysters in the Blackwater Estuary was estimated as 10^5 and in this case the radioactive zinc concentrated by the oysters was found to be the limiting radioisotope in which effluent discharge rates from Bradwell Power Station were based⁽³⁾. It follows that one essential quantity for the correct determination of concentration factors is the actual concentration of the element in the organism. This concentration at a given time is the result of the dynamic processes of uptake and loss by the organism, regulated, in part, by the abundance and chemical or physical form of the element in the environment, the chemical composition of the organism, and the physiological or biochemical activities within the organism itself. With so many variables involved it might be expected that the actual concentration of an element in an organism would vary, though significantly, in general, concentration factors are quoted as single values for a particular isotope and organism.

The work described in this article deals with the variation in element concentration in a marine organism as a function of time, and the influence of this variation on the correct evaluation of concentration factors for use in practical assessments on the permitted limits of discharge of radioactive effluent to the marine environment for purposes of public health control.

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TABLE I.
Exposure factors involved in the discharge of aqueous radioactive wastes in the United Kingdom.

	<i>Site</i>	<i>Critical material</i>	<i>Critical exposure category</i>	<i>Exposed group</i>
1. ENGLAND & WALES				
<i>U.K.A.E.A.</i>				
Windscale	Porphrya (laverbread)	Beta dose to G.I. tract	General public (S. Wales)	
Winfrith	Lobster and crab flesh	Beta dose to G.I. tract	Local fishermen and families	
Springfields	Silt	Gamma dose to whole body	Dredgermen (Preston Docks and Harbour Board)	
Aldermaston				
Harwell				
Amersham				
<i>C.E.G.B.</i>				
Berkeley	Silt	Salmon fishermen		
Bradwell	Shrimp and salmon flesh	Local fishermen and families		
Hinkley Point	Oyster flesh	Oyster fishermen and families		
Trawsfynydd	Flashfish and shrimp flesh	Local fishermen and families		
Dungeness	Silt	Local fishermen and families		
Oldbury	Trout flesh	Local fishermen and families		
Sizewell	Fish flesh	Local fishermen and families		
	Silt	Local fishermen and families		
	Shrimp	Oyster diggers		
		Salmon fishermen		
		Local fishermen and families		
		Local fishermen and families		
2. SCOTLAND				
<i>U.K.A.E.A.</i>				
Dounreay	Detritus (salmon fishing net)	Beta dose to hands	Local fishermen	
Chapelcross	Beach sludge	Gamma dose to whole body	Local fishermen and others	
	Shrimp flesh	Beta dose to G.I. tract	Local fishermen and families	
	Sea shore	Gamma dose to whole body	Winkle collectors	
<i>S.S.E.B.</i>				
Hunterston	Fish flesh	Beta dose to G.I. tract	Local fishermen and families	
	Sea shore	Gamma dose to whole body	Winkle collectors	

Radioactivation Analysis

The success of such an investigation rested on the ability to assess accurately the quantity of stable element present in the organism. In this sense the problem was common to all work of this nature, where one is generally dealing with very small quantities of metallic trace elements. Thus an important facet of the work was to develop a technique for quantitative trace element determination, and the availability of a nuclear reactor permitted the use of neutron activation analysis. The reactor employed was the Jason 10 kW research reactor situated at the Royal Naval College, Greenwich, a detailed description of which is given elsewhere⁽⁴⁾.

Activation analysis is one of the most rapidly developing analytical techniques at the present time and is well suited to elemental micro-analysis where it possesses several advantages in comparison with other methods. There is generally a very high potential sensitivity which is often greater than other methods of trace analysis and in some favourable cases detection of less than 1 μg of element is possible.

The essential basis of the method is that the stable element under consideration is made radioactive as a result of neutron bombardment in a nuclear reactor and this induced radioactivity is used as a measure of the mass of element originally present. A comparator technique is generally used in which a sample is irradiated simultaneously with a standard containing a known quantity of the element of interest. If the induced activity of the sample and standard are measured under similar conditions the unknown quantity of the element in the sample may be readily calculated⁽⁵⁾.

The object of this work can therefore be defined as the development of the technique of neutron activation analysis for the quantitative determination of trace elements in marine organisms and its application to the study of the seasonal variation in element concentration in such organisms.

Choice of Element and Organism

The specific variable investigated was the variation with time in the stable manganese content of the mollusc *Crassostrea angulata* (Portuguese Oyster). The reasons for this choice are outlined below.

Manganese is one of the so-called 'essential' trace elements and whilst there is no knowledge of the exact ecological significance of this element⁽⁶⁾ it has been shown^(7,8) to be essential to life, growth and development of all organisms. Its main function is as a catalytic enzyme activator and it resembles magnesium in activating a num-

ber of phosphate transferases and decarboxylases, notably occurring in the Krebs Cycle.

The radioisotope manganese 54 formed by the nuclear reaction $\text{Fe}^{54} (\text{n}, \text{p}) \text{Mn}^{54}$, with a radioactive half-life of 291 days, is of particular interest as one of the neutron-induced nuclides produced as a result of nuclear weapons testing⁽⁹⁾; it also forms part of the active waste from nuclear powered shipping⁽¹⁰⁾ and certain land-based installations disposing to coastal waters. It appears likely therefore that increasing quantities of this radioisotope will reach the environment and of particular relevance in this context is the success of the Advanced Gas Cooled Reactors which suggests the likelihood of their introduction on a much wider scale in the early 1970s. If this becomes the case then increased quantities of manganese 54 from the stainless steel cladding of the fuel elements are likely to reach the marine environment through cooling ponds, in much the same way as zinc 65 from the magnox fuel element cladding of the Calder Hall type reactors at Bradwell, referred to earlier, enter the Blackwater Estuary.

Work by Merlini⁽¹¹⁾ substantiated by Polikarpov⁽¹²⁾, demonstrated high concentration factors for manganese in molluscs. Furthermore Vinogradov⁽¹³⁾ indicated that the lamellibranchiata to which the oyster belongs, were the group of molluscs with the highest content of manganese in their tissues. Consequently the probable increase in abundance of manganese 54 in the environment together with the apparent ability of oysters to concentrate this essential element suggested that this important commercial food should be high on the list for investigation as 'critical material' in an environment containing radiomanganese. Consultation with the Ministry of Agriculture Food and Fisheries radiobiological laboratory at Lowestoft, revealed that regular monthly supplies of commercial Portuguese oysters were being collected over a period of years and this material was kindly made available for this work.

Measurements of Induced Radioactivity

Frequently interference from radioisotopes induced in a sample matrix during irradiation complicates or obscures the identification of a trace element which is to be measured. Consequently the choice of method adopted for the measurement of activity of an irradiated sample is largely governed by the activity of the element to be determined relative to the total activity of the sample (the decay characteristics of the active species being the other major consideration). In general, analysis subsequent to activation can be broadly divided into two types, namely, those involving chemical separation and those employing purely

physical instrumental methods. Chemical separations are usually devised to yield the element to be determined from the active sample material, eliminating either wholly or partly the interfering activities induced in the matrix macro-constituents. Non-destructive purely physical methods of analysis such as gamma-ray spectrometry or coincidence counting techniques seek to eliminate the shortcomings of resorting to chemical methods. The choice between these approaches is by no means obvious and very often physical techniques have to be supplemented by some chemical separation in order to eliminate at least some of the interfering activities. This is particularly so when a small yield of a radioisotope is sought in the presence of a highly active matrix, or the maximum sensitivity is required.

The potential application to the determination of manganese in oysters of both gamma spectroscopy and beta-gamma coincidence counting were investigated together with the possible use of allied radiochemical separations. These investigations are fully documented⁽¹⁴⁾ and led to the conclusion that purely physical non-destructive gamma-ray scintillation spectrometry, in conjunction with a multi-channel pulse height analyser, offered the most suitable method of approach. Briefly, this method involves the absorption of radiations from the active sample in a scintillation crystal. Resultant pulses whose amplitudes are proportional to the energy absorbed in the crystal are transmitted via a photomultiplier tube into a multi-channel analyser. The analyser accepts and amplifies pulses from the detector, grouping them into small bands according to their amplitude. The presentation of the characteristic energy distribution from the active sample is generated in analogue form and displayed on a cathode ray tube. Analogue to digital conversion of the energy distribution data by the analyser converter section may be automatically typewritten or punched in binary coding on paper tape.

In this work a 400 channel analyser together with a 3" × 3" Sodium Iodide Thallium activated crystal was used (Fig. 1) and the resulting energy spectrum from an activated oyster sample using this equipment is given in Fig. 2. The physical phenomena which occur in the detector unit and the profound influence of interfering matrix activities producing the particular shape of this spectrum are described elsewhere^(14, 15). For the purpose of this article it is sufficient to appreciate that the manganese photo peak of interest (Fig. 2) resulting from gamma ray emissions from radioactive manganese 56, appears as a discrete peak amongst several other interfering activities, notably sodium 24.



FIG. 1. Multi-channel analyser unit.

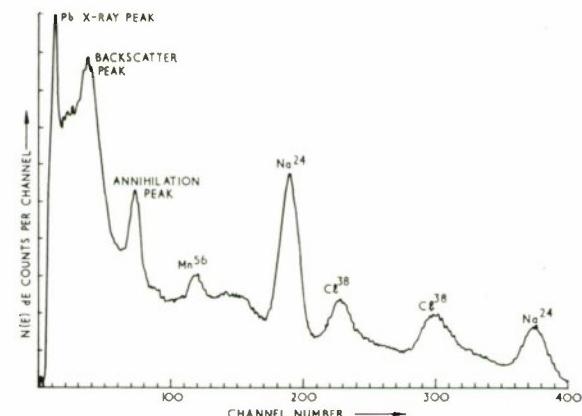


FIG. 2. Gamma spectrum of an activated oyster.

Quantitative Analysis of Spectra

Comparative measurements of gamma spectra generated on a multi-channel analyser can be made by determining the photo-peak area of a given gamma ray in an unknown sample and that of the same gamma ray in the spectrum of a comparator standard. In order to estimate the correct gamma ray abundance utilising peak area evaluation methods^(16, 17), it is necessary to deal only with that area of the photo-peak above the background level and this area must be free from contributions of gamma rays from other nuclides. If the spectrum is complex with overlapping photo-peaks the only practical methods of resolving the components are either by least squares analysis^(18, 19, 20) or by spectrum stripping techniques^(21, 22). Both these methods require some form of standard spectra library with which the unknown spectrum is compared and it is this comparison

that determines the accuracy of the procedure, success depending upon the inclusion of all appreciable impurities present in the sample in the library used. Briefly, in the least squares analysis, for spectra of unknown composition, analysis of peaks is performed by non-linear least-squares analysis on the assumption that the total absorption photo-peaks are gaussian in shape. The contribution of each component within a mixed spectrum is calculated so that when these are added together, the closest fit (in a least squares sense) to the observed spectrum is obtained; for spectra of known composition, linear least squares analysis can be performed. In spectrum stripping each component of the complex spectrum is unfolded in turn starting with the most energetic photo-peak. The unscrambled spectrum of the desired component is compared with that of the respective library standard to determine its concentration.

There are many variations on these three themes but a problem common to all lies in the stabilisation of the energy spectra generated to ensure that in any comparison corresponding portions of sample and standard spectra are employed. This major difficulty is discussed later and it can be overcome by gain and base stabilisation, either using mathematical manipulative techniques on the generated spectra^(14, 23, 24) or by direct instrumental stabilisation such as is incorporated in the modern digital stabiliser to permit gain and base stabilisation whilst the spectrum is being accumulated.

Due to the discrete nature of the photo-peak of interest in this work (Fig. 2) the situation appeared to lend itself to peak area evaluation methods and satisfactory investigations were conducted to ensure that this particular photo-peak was free from contributions from other nuclides. Consequently it was decided to adopt the peak area evaluation approach based on a method by Covell⁽¹⁶⁾ which utilised the digital nature of the pulse height distribution data provided by the multi-channel analyser. These data are stated in counts per unit increment of amplitude and individual channel responses can be represented graphically as rectangles whose areas are directly proportional to the number of counts observed in the channel. Fig. 3(A) shows a typical pulse height distribution curve in the region of a photo-peak, displayed graphically in accordance with the above representation. If the contributions between i and j are added, the sum represents the total number of counts contained in these channels and is represented graphically in Fig. 3(a) as the area $\bar{A} + A$. Within the statistical variations in the counts contained in the several included

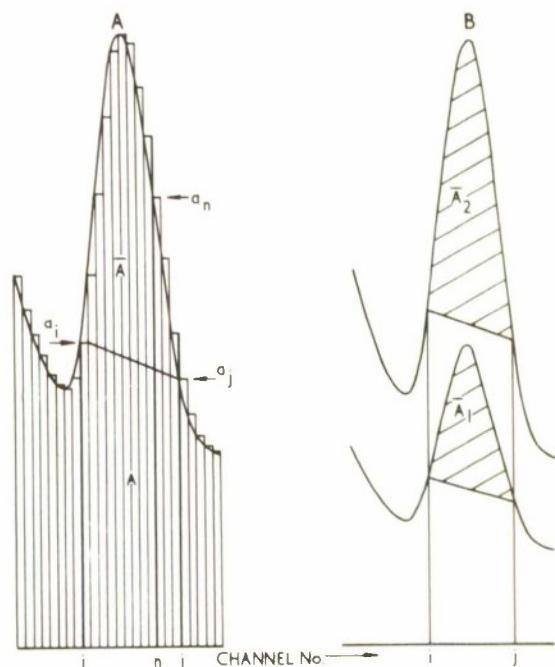


FIG. 3. A and B. Pulse height distributions.

channels, \bar{A} bears a constant relationship to the total area contained in the photo-peak. If the number of counts in the n^{th} channel is given by a_n , then

$$\bar{A} = \sum_{n=i}^j a_n - (a_i + a_j) \left(\frac{j-i+1}{2} \right) \quad (1)$$

If a sample and standard are subject to the same irradiation conditions then the radioactivity R resulting from the activation of m grams of an element measured at a time T after termination or irradiation is given by

$$R = K m \left(\frac{1}{2} \right)^{T/\tau}$$

where K is a constant and τ the half-life of the induced radioisotope. Using suffix I to denote a sample and suffix 2 a standard, let

M_1 = Mass of oyster material forming sample

M_2 = Mass of oyster material forming standard

w = Mass of manganese added to form the standard

m_1 = Mass of manganese in M_1 of sample

m_2 = Mass of manganese in M_2 of standard.

Then from equation (2)

$$\frac{R_2}{R_1} = \frac{(m_2 + w) \left(\frac{1}{2} \right)^{T_2/\tau}}{m_1 \left(\frac{1}{2} \right)^{T_1/\tau}} \quad \dots (2)$$

Assuming a homogeneous sample material $m_2/m_1 = M_2/M_1$, then

$$m_1 = \frac{w(\frac{1}{2})(T_2 - T_1)/\tau}{\frac{R_2}{R_1} - \frac{M_2}{M_1} (\frac{1}{2})} \quad \dots (3)$$

From the foregoing discussion the ratio R_2/R_1 can be represented by \bar{A}_2/\bar{A}_1 (Fig. 3(B)), the ratio of corresponding photo-peak areas of standard and sample calculated from equation (1). The mass of manganese in the sample material can therefore be calculated from equation (3) since all other terms are measurable.

The accuracy achieved with this approach depends largely on the accuracy with which the photo-peak area can be calculated. This in turn is decided by two major considerations, namely, the statistical accuracy of the calculated area and the ability to select corresponding portions of the sample and standard photo-peaks in the areas under comparison.

For a given situation the former consideration is predictable in that the variance (V) of a calculated area can be obtained directly from equation (1) using basic statistical methods:

$$V(\bar{A}) = \sum_{n=1}^j a_n + \left\{ \left[\frac{j-i-1}{2} \right]^2 - 1 \right\} (a_i + a_j) \quad \dots (4)$$

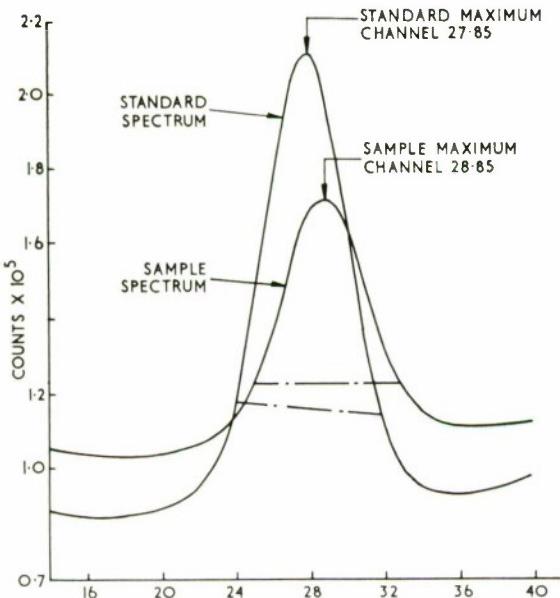


FIG. 4. Superimposed plots of oyster standard and sample, showing relative drift

The root of the variance expressed as a percentage of its associated calculated area yields the desired probable percentage error on that area. Initial investigations on oyster samples revealed that for the experimental design adopted, an error of about 10% on a single calculated area was probable. However, since the error involved was directly proportional to the root of the variance and inversely proportional to the area it was apparent that an increase in area would result in a reduction in error. The desired increase in area was achieved by increasing the count rate and counting time and reducing the number of channels spanning the photo-peak, when the error was reduced to less than 1% on a calculated area.

The second consideration in the selection of appropriate areas for comparison is associated with the problem of spectrum stabilisation referred to earlier. It is clear from Fig. 4 that if relative drift between an activated oyster sample and compared standard exists then area comparison between say channels 24 and 32 for each of the spectra will result in error. Observations on typical oyster sample and standard spectra indicated that relative drifts of a channel or so were commonplace and a series of experiments was conducted to examine possible contributory causes of drift. These investigations included analysis of the effect of pulse pile-up, voltage instability, temperature fluctuations and the effect of count rate on spectral location. Briefly, pulse pile-up is the name describing the condition which exists when more than one pulse occurs during the amplifier resolving time. Pulse super-position occurs and the spectrum is displaced towards higher energies. Voltage stability is extremely important because in a photo-multiplier tube the secondary emission ratio (S.E.R.) is roughly proportional to the voltage between dynodes. For 'n' dynodes, an overall current gain of (S.E.R.)ⁿ results and it follows that a well stabilised system is essential if gain drift (with accompanying spectrum shift) is to be avoided. Relatively small changes in temperature between the time of counting the sample and compared standard can have a significant effect on drift since the gain of a photo-multiplier tube is a function of its temperature. This gain shift is dependent on the wavelength of light incident on the photocathode; these effects have been studied for various tubes from room temperature to liquid nitrogen point⁽²⁵⁾.

It was found that the major cause of drift in the equipment used resulted from gain changes in the photo multiplier tube due to variation in count rate. (It will be appreciated that the response of any system is a function of its component parts as an entity and a different system may have an entirely different response.) The only

other significant contribution arose from temperature fluctuation producing a spectrum drift of about one half of a channel per degree centigrade. The predominant conclusion drawn however, was that whatever the count rate of an active oyster sample may be, the inevitable difference in the count rate of the standard would result in the compared photo-peaks appearing at different energy levels. Thus a situation such as depicted in Fig. 4 with a drift between the compared spectra was prevalent and the influence of this drift on the accuracy of photo-peak area evaluation required examination.

Peak Area Evaluation Techniques

As previously indicated, comparison between channels 24 and 32 for each spectrum of Fig. 4 is untenable since incorrect portions of the photo-peaks would be involved. Covell⁽¹⁶⁾ in his application went a long way towards obviating the discrepancy by treating the sample and standard spectrum separately, taking the peak channel of an individual spectrum as a datum to define the area limits. This approach is precisely correct provided the relative drift between spectra is an integral number of channels, but inaccuracies occur in the case of non-integer relative drift⁽¹⁴⁾.

An alternative method of approach used commercially is based on re-location of compared spectra in integer channel positions before attempting comparison. The raw data of a generated spectrum is used to find the true, generally non-integer, maximum channel position for the photo-peak. This is achieved by applying a linear least

squares fit to data of the form $\log e^{\frac{a(n-1)}{a(n+1)}}$ obtained from Zimmermans technique for finding the maximum peak position⁽²⁶⁾. Knowledge of this peak position permits calculation of the spectrum displacement necessary to position the peak value in an integer channel position. The new distribution of channel counts about this position is estimated on the assumption that a linear count distribution exists between successive channels of the original spectrum. Thus referring to Fig. 5(A), for a non-integer displacement F between the original and re-located spectrum, the original count a_i in the i^{th} channel becomes a_i^* in the re-located spectrum and

$$a_i^* = a(x) \text{ at } x = (1-F)$$

$$\text{but } a(1-F) = (a_i - a_{(i+1)})(1-F) + a_{(i+1)}$$

$$a_i^* = a_i(1-F) + F a_{(i+1)}$$

Successive application of this latter equation to each channel of the original spectrum results in the generation of a new series of data comprising the re-located spectrum whose peak value appears

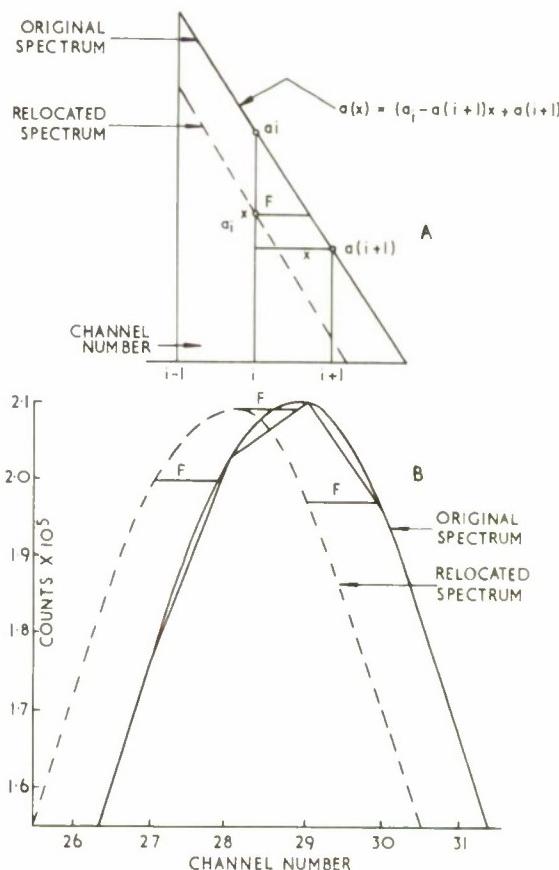


FIG. 5. A and B. Spectrum relocation.

in an integer channel position. This procedure carried out for both samples and standard spectra creates conditions suitable for the application of Covell's method to the re-located spectra by eliminating non-integer channel drift. However, the assumption that a linear count distribution exists between successive channels in determining the re-located spectral data is suspect. Fig. 5(B) shows a comparison of the original and re-located oyster standard spectrum in the region of the peak values. It will be appreciated that the assumed linear distribution between channels in this vicinity is not valid and is reflected in a somewhat depressed re-located spectrum about the peak position, which could lead to error in analysis.

It was concluded that both the 'COVELL' and 'RELOC' methods had inherent sources of error and since the nature of the work demanded a high degree of accuracy it was decided to attempt to evolve an alternative more accurate approach. A suitable method named 'BARLINE' was developed which was completely independent of relative spectrum drift. The essential feature of this original

method is that an imaginary straight line (the *BAR-LINE*) is fitted into each of the compared spectral distributions in turn. Thus in Fig 6(A) if the two triangles shown representing the distribution of counts for a standard and sample are in the ratio of 2 : 1, then a horizontal barline of fixed length fitted into these distributions results in an area ratio of 2. This is true for any barline length and is quite independent of any relative horizontal drift of either spectrum.

The data from a multi-channel analyser does not provide the distribution of counts in the sense used above, but rather the counts collected in a given energy increment. The histogram of Figure 6(C) demonstrates this, where each channel count is clearly associated with an area represented by a rectangle of one channel width. Referring to this diagram, the fitting of a horizontal barline requires a knowledge of the count distribution between channels, since in general, such a barline would not fall at an integer channel position on both sides of the photo-peak. Assuming a linear distribution of counts between channels, the dotted line LM gives the distribution of counts between channels 2 and 3. Likewise for the right hand side of the photo-peak, the dotted line KN yields the appropriate distribution between channels 7 and 8 and these distributions permit the correct positioning of the barline PQ. Following the previous nomenclature of a_n being the number of counts in the n^{th} channel the area above PQ is given by the equation.

$$A = \sum_{n=4}^7 a_n + (\overline{MA} - \overline{PA}) + \overline{BQ} - \overline{PQ}$$

where \overline{MA} denotes the area enclosed between MA and the baseline etc.

$$\begin{aligned} \text{If } \sigma_1 &= (a_3 + a_2) & \sigma_2 &= (a_3 - a_2) \\ \sigma_3 &= (a_7 + a_8) & \sigma_4 &= (a_7 - a_8) \end{aligned}$$

Then using the necessary conditions $a(P)=a(Q)$ and that the horizontal displacement Z of P from A must be equal to the horizontal displacement of Q from B, the above equation can be re-written as

$$A = \sum_{n=3}^7 a_n + \frac{(\sigma_2 - \sigma_1)^2}{8(\sigma_2 + \sigma_4)} - \text{NBAND} (\sigma_2 Z - \sigma_1 / 2) \quad \dots (5)$$

NBAND is the selected barline width in channels and all other terms in equation (5) are directly obtainable from the raw multi-channel analyser spectral data.

The foregoing relates specifically to a horizontal barline fitted to a spectrum with a horizontal baseline. The influence of a sloping background in a more general case is apparent from an examination of Fig. 6(B). If the areas com-

pared are those above the dotted lines, representing a horizontal fixed length barline, then an erroneous area ratio results. To obtain the correct area ratio the fitted barline must be parallel to the spectrum baseline. The most convenient method of applying the barline technique in the case of a spectrum with a sloping baseline, is to adjust the spectrum so that the photo-peak rests on a horizontal baseline. This can be done by taking the minimum value on both sides of the photo-peak, from which the baseline slope in counts per channel can be calculated. Subtraction of the appropriate number of counts in each channel over the photo-peak will result in a 'backstripped' spectrum on a horizontal baseline. Care must be taken in determining the minimum values at the foot of the photo-peak and some smoothing of the raw channel data is desirable. This can be satisfactorily achieved by assuming a cubic distribution to exist through five points about the apparent minimum value, whence a polynomial least squares fit through these points yields the position and magnitude of the best minima.

Summarising, the barline technique applied to a sample and standard photo-peak area comparison requires that each spectrum be partially

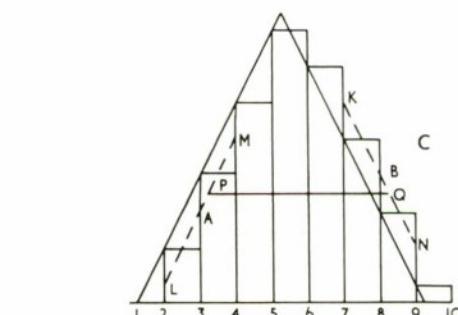
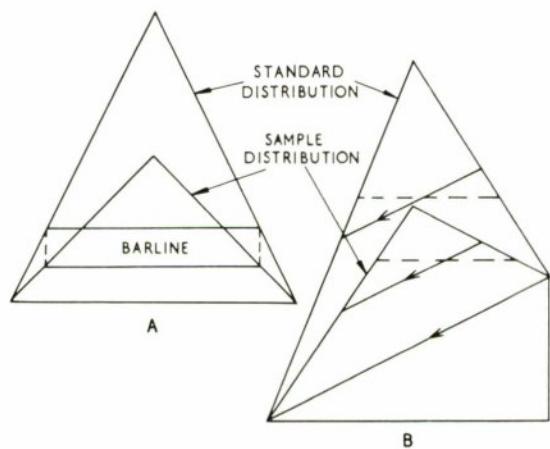


FIG. 6. A, B and C. Theoretical/Barline application.

stripped so that the photo-peak lies on a horizontal background. A horizontal fixed length barline is then fitted to each distribution in turn ensuring that comparison is made using appropriate areas.

Computer Data Processing

A series of controlled experiments was conducted to test the validity of the barline method and its relative merit in comparison with the Covell and Relocation approaches. In order to facilitate the considerable data processing involved, a computer programme was written incorporating application of all three methods on sample and standard tapes fed directly from the multi-channel analyser to the computer⁽¹⁴⁾. The computer complex used consisted of an IBM 1620 computer with Disk Storage and Monitor System. The programme written in Fortran II D language was too large to be accommodated in the central processing unit and necessitated utilisation of the monitor system. This facilitated the summoning by a mainline controlling programme, any of eight sub-programmes stored on disk, to the central processing unit for execution.

This programme, used in conjunction with experimental and statistical analysis, repeatedly indicated that the *Barline* technique was superior to both the Covell and Relocation methods. The results of the analyses can be summarised as follows. At all times the accuracy and precision of *Barline* was better than that of Covell (accuracy being defined as the ability to obtain the correct answer; precision as the reproducibility of an experimental result). Comparison of individual values obtained by the two methods revealed that although there was no obvious direct relationship, a clear trend existed which indicated that the difference in the *Barline* and Covell values increased with increased non-integer relative spectrum drift. The Relocation technique was inferior to both other methods. Significantly, where no relative drift existed between sample and standard spectra, relatively poor results reflected implementation of relocation with its inherent source of error. (It will be appreciated that even with no relative spectrum drift, relocation occurs unless the peak value coincides with an integer channel position.) Consequently it was decided to adopt *Barline* as the method of analysis in the specific problem of the determination of the seasonal variation in the manganese content of oysters.

Oyster samples collected over a period of two years were therefore prepared for activation and subsequent analysis using the computerised *Barline* technique. Discussion of these analyses is withheld to permit an essential summary of sources of error encountered in this work associated with

the technique of activation analysis. In this context it is important to appreciate that standards were made up by adding a known quantity of "Specpure" manganese in solution, to a similar quantity of oyster material used in making up the sample. As will emerge in the following section the resultant close physical and chemical similarity of the sample and standard has a profound influence on minimising errors peculiar to the activation process.

Errors Associated With Activation

The essence of the problem lies in the fact that the simultaneous irradiation of two similar samples under apparently identical conditions in a reactor, may result in different induced specific activities. There are several possible sources for such a discrepancy and these include flux inhomogeneities at the irradiation position, self-shielding within a sample, interfering nuclear transmutations associated with the sample matrix, sample inhomogeneities and processing errors associated with pre-irradiation contamination of sample material. A brief discussion of each of these phenomena together with their relevance to this work follows. The space available dictates the omission of the experimental details forming the basis of the summarised conclusions.

(a) Flux inhomogeneities

The normal or unperturbed flux in a reactor is not uniform and a spatial flux gradient may exist in the vicinity of an irradiation position. Thus a sample and comparator standard activated simultaneously in adjacent positions, may be exposed to fluxes of different magnitude resulting in an error in the induced specific activities. This spatial flux gradient can be quite large, particularly near the reactor reflector. In certain facilities the neutron flux changes drastically over a distance of only a few inches, whereas in others there is little change over the distance of a few feet. Experiments revealed that for the irradiation position in the reactor used in this work, a spatial flux gradient of 1% per cm existed.

(b) Self-Shielding effect

In a sample of finite thickness the neutron flux becomes progressively smaller in magnitude towards the centre of the sample as succeeding layers absorb neutrons. If this did not happen, or happened to a different degree in the standard against which the sample was being compared, then different specific activities would result and the error in analysis would be dependent upon the difference in the two self-shielding effects. Because of the almost identical nature of the standard and sample in this work it was expected that self-shielding effects were likely to be unimportant.

However, the fact that the standard contained roughly twice as much stable manganese as the sample meant that, because of this isotope's high thermal neutron cross section, there was a possibility of a greater degree of self-shielding in the standard. Experimental determination demonstrated however that the presence of this additional manganese had no measurable effect on the relative specific activities simultaneously induced in samples and standards. It was therefore concluded that any effects due to self-shielding were common to both and consequently errors due to this phenomena negligible.

(c) *Interfering nuclear transmutation*

In addition to the activation reaction occurring with the element under determination in an analysis, it is possible for the same sought radioisotope to be produced from activation reactions in the matrix material and other impurities present. For example, in the determination of manganese in an iron-rich matrix, activation production of manganese 56 resulting from the $Mn^{55}(n,\gamma)Mn^{56}$ reaction will be accompanied by production of this radioisotope by the $Fe^{56}(n,p)Mn^{56}$ reaction. If such interfering reactions are significant in the production of the radioisotope forming the basis of the analysis then the comparison will be in error.

Calculations on the magnitude of manganese 56 activity likely to result from interfering reactions, based on nuclear data applied to the relative abundance of elements present in the sample matrix, indicated that the formation of manganese 56 from anything other than stable manganese was unlikely to exceed 0·001% of the manganese activity produced. It was concluded that the effect of interfering nuclear transmutations could be ignored.

(d) *Sample inhomogeneities*

In taking a small quantity of ash (20 mg) from the main body of sample material, the question arises as to how representative this sample is of the main mass, comprised of some 100 to 150 freeze-dried and ashed oysters. Clearly any relative inhomogeneity between the sample and the sample material used in making up the standard would be reflected in their relative specific activities. Experiments designed to assess this effect indicated the existence of a certain amount of inhomogeneity which could result in a 1% error in the induced specific activities of simultaneously activated samples and standards.

(e) *Processing errors*

Sources of error associated with the treatment of samples before and after irradiation can be loosely described as processing errors. The major

source of processing errors arises in the pre-irradiation preparation of material, since subsequent operations should not introduce radioisotopes. It was established that direct sample contamination in the preparation of the ashed oyster material was negligible but the transfer of the ashed material to the irradiation capsule required attention.

It was estimated that a single handling of the polythene capsules used would result in a contamination level of 0·4 μ g of sodium and 2×10^{-5} μ g of manganese. To eliminate any contamination problems thus arising from sample encapsulation, several cleaning and handling routines were tested. The technique finally adopted included washing the capsules in a warm weak acid bath, flushing with de-ionised water then rubbing clean with acetone. Subsequent handling was carried out with disposable polythene gloves and perspex forceps. Irradiation of empty capsules thus treated demonstrated that virtually no radioactivity was induced over the activation period and counting time envisaged.

It will be appreciated that many other factors apart from those indicated above are involved in the correct assessment of induced specific activity, but the remainder are more general sources of counting error common to any determination of radioactivity and not peculiar to the activation process in particular. For this reason they are excluded from the discussion despite their importance to satisfactory analysis. Suffice it to say in summary that the major contributions to error in specific activity determinations in this work was a consequence of the activation errors of flux gradient and sample inhomogeneity. It was estimated that a 2% difference in the specific activities of simultaneously irradiated samples and standards could result from these sources and utilisation of a flux monitor factor was incorporated into the computer calculations to minimise this error. This factor was simply a direct multiplier on the ratio of the measured induced manganese activities (equation 3) which provided a single correction for both flux and sample inhomogeneities.

The principle underlying the use of this factor depended upon allowing the manganese analysed sample and standard to decay until the remaining residual activity was virtually due to radioactive sodium 24 alone. Under these circumstances any difference between the specific sodium activities of the sample and standard indicated flux or sample inhomogeneity. The ratio of these activities provided the factor used in calculations, since the manganese activities would differ by the same fraction.

Application of the factor to the analysis resulted in an improvement in absolute accuracy at the expense of some precision. This was a consequence of the imprecision in estimating the factor itself. Despite this, in view of the unsystematic nature of the error involved, it was considered justifiable and necessary to sacrifice a little precision in favour of improved accuracy. Consequently, for the investigation into the seasonal variation in the manganese content of oysters, the computerised *Barline* technique with flux monitor factor incorporated was adopted.

Experimental determinations together with statistical analysis of data indicated an overall accuracy of better than 5%, which was considered satisfactory for dealing with biological material.

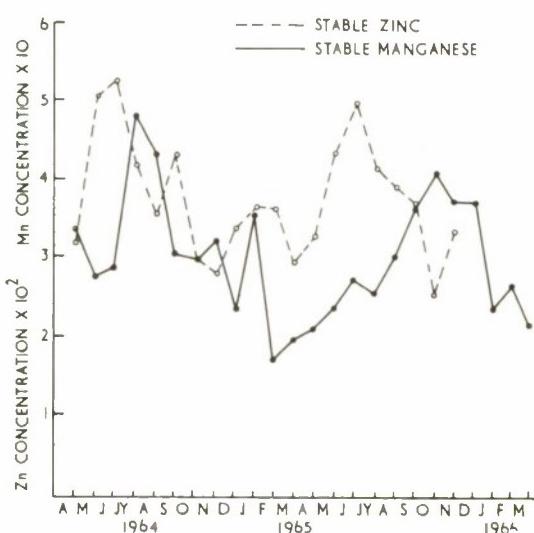


FIG. 7. Comparison of stable manganese and zinc concentrations in dry oyster flesh over a period of two years.

Results and discussion

The object of this work was to develop a practical technique for the quantitative determination of trace elements in marine organisms and to apply this technique to a specific study of the seasonal variation in the stable manganese content of Portuguese oysters.

Considering the latter aspect first; Fig. 7 shows clearly that the initial postulate that the manganese content of oysters was likely to vary with time was correct. The unbroken line on this graph represents the variation with time in manganese concentration, in parts per million dry oyster flesh, over the two year period investigated. A substantial variation in concentration amounting to a factor of three in terms of the extreme values is observed. A rough cyclic pattern exists which suggests that

seasonal variation with peak values occurs in the autumn, although maximum concentrations in the second year occur somewhat later than those of the first year. It can be argued that in dealing with biological material in the natural environment, conditions of temperature, tidal flow and food supply may alter the precise timing from year to year. Of interest is the dotted line superimposed on Fig. 7 which represents the variation in stable zinc concentration in the same oysters over the period⁽³⁾. A similar pattern emerges, with the manganese peaks being somewhat out of phase with those relating to the zinc. Incomplete data on copper⁽²⁷⁾ show the same trend, with the copper peaks out of phase with both the zinc and manganese peaks and lying between them each year.

The fact that the manganese concentration in the oysters varies by a factor of three, casts suspicion on the generally adopted procedure of quoting a single value of the concentration factor for a particular element and organism. Bearing in mind however that the International Commission on Radiological Protection⁽¹⁾ in their recommendations are concerned with average levels of radioactive intake over 13 or 52 week periods, such a procedure is acceptable provided the concentration factor used in calculations is an average value which allows for seasonal variation in concentration. It is therefore important to derive concentration factors from a large number of samples obtained over a representative period of time of at least a year in the environment in question. In many cases however the concentration factors quoted in the literature are based on isolated observations obtained by outdated and unreliable analytical methods. It is interesting to note that the only reference appearing in the literature relating to the manganese content of *Crassotrea angulata*⁽¹³⁾ gives a concentration of 6 µg/g of wet oyster flesh. This compares with an average of 11·6 µg/g obtained in this work for the legal marketing period of July, August and September of 1964 involving a factor of two in estimates of the concentration factor.

Concentration factors are of fundamental importance in practical assessments of permitted rates of discharge of radioactive effluent to the marine environment. The demonstrated variation in the manganese concentration of the oyster investigated highlights one of the difficulties associated with obtaining a good estimate of the concentration factor, namely, representative sampling in time, environment being the other major consideration.

The other and more generally applicable aspect of this work, namely, the development of an accurate method of quantitative trace element

determination using activation analysis, has resulted in an original method of photo-peak area evaluation which the author named the "Barline" technique. The consistency achieved in the experimental results has demonstrated that this new method is superior in precision and accuracy to either of the two commercially used methods described in this paper. This is not to say that Barline is without its disadvantages, and in the event of a computer not being available for data processing, then the Covell method provides the best alternative approach, in that it lends itself to manageable hand computation. A limitation that should be emphasised, which applies to any type of photo-peak area evaluation, is the pre-requisite of a discrete photo-peak above the spectral Compton continuum. Minor undulations in the continuum over the photo-peak energy span are not significant, but the presence of an additional underlying photo-peak from another nuclide would probably affect correct area comparison.

Finally it is perhaps worth mentioning that apart from its use in activation analysis as applied to this work, the Barline technique has considerable application in gamma spectrometric analysis in general, as an accurate method of photo-peak area evaluation. For example, monitoring of the levels of various isotopes present in the coastal waters of this country are continually and increasingly being conducted using gamma spectrometric methods and there is undoubtedly a place for an accurate and adaptable method of photo-peak area evaluation such as the Barline technique offers.

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TIME

Musical Clock
circa 1770



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*"'Tis well—since all humanity must brave
The doubtful current of Time's mighty river."*

Henry S. Leigh—1868.

CHE recent publication of two very interesting articles on Time^(1, 2) emphasises the constant preoccupation of men's thoughts with the unsolved mysteries of Nature. As we surmount each barrier to knowledge our vantage point reveals new vistas, fresh horizons appear and the uncharted areas around us seem ever larger than before. Yet a backward glance shows that a great deal of that which we take for granted is just as unknown as that which lies before us. This applies just as much to our basic concepts as to any other part of the structure of knowledge.

Within the present universe, man alone, as far as we can tell through the use of our strictly limited senses and intelligence, has the power of abstract thought necessary to contemplate the basic structure of the physical universe and the laws which govern its behaviour. With this power is the ability to direct such thought into a given time setting. We can contemplate past events or we can envisage future happenings.

What exactly is time? No one yet has been able to give a completely satisfactory definition. Many have attempted to do so. One thousand five hundred years ago Aurelius Augustinus, Bishop of Hippo in North Africa, philosopher and later saint; expressed the dilemma thus: "What then is time?" he asked, "If someone asks me I know. If I wish to explain it to someone, I know not".⁽¹⁸⁾ Sir Isaac Newton, who encircled the whole universe in the mantle of his thought, considered that time was a uniform flow.⁽³⁾ He did not state the nature of what was flowing. The plain unvarnished

truth is that even to-day no one knows the answer to this problem. Like all other phenomena around us, time can only be detected as a result of some change. The passage of time is that something which allows successive events to take place, but what that something consists of is just as much a mystery to us to-day as it was to the first man who considered the problem. Fortunately our ignorance of the nature of time does not prevent our utilization of its passage any more than our ignorance of the precise nature of electricity prevents us from putting it to good use in our factories and homes.

Time is often compared to the flow of a river, but as an analogy it is not a particularly good one. Rivers tend to have a variable flow and the flow may be stopped or reversed where the river meets the sea. It seems almost intuitive that time should have a uniform flow but equally there seems no valid reason why it should not be possible to halt and perhaps even to reverse time. However we are all aware that time appears to pass at a varying rate according to our particular mood. If we are bored, time passes slowly, if we are happy or fully occupied, time flies. When we are driving a car and some incident occurs which is likely to involve us in an accident, events happen as though in a slowed-down film, i.e. time is speeded up for us. All these effects are merely a product of the activity of the brain of the person concerned, the actual time proceeds quite normally. Again, who has not at some time or another wished to be able to turn back the hands of the clock in order to rectify some erroneous action or accident of fate?

The observation that time cannot be reversed is evidently very old indeed as is shown in the first written record of a time-measuring device. It is mentioned in two places in the Bible, 11 Kings, Chapter 21, verses 9 - 11; and Isaiah, Chapter 38, verse 8; the event is known as the miracle of Isaiah. Time measurement was something to be taken for granted, even then, as it is only mentioned in order to demonstrate the miracle. For those who are not familiar with the Bible, the story of the miracle of Isaiah concerns the sign given to King Hezekiah to assure him of the certain recovery from his illness and that God would grant to him a further 15 years of life. When Isaiah asked the King what positive sign from the Lord would satisfy him, King Hezekiah requested that the shadow of the sun-dial of Ahaz be returned, *i.e.* time should be turned backwards; a miracle sufficient to impress unbelievers even to-day. Isaiah said, "Behold I will bring again the shadow of the degrees, which is gone down in the sun-dial of Ahaz, 10 degrees backwards. So the sun returned 10 degrees, by which degrees it was gone down". It was proof enough for the King, who promptly recovered from his illness and continued to reign for his allotted number of years. King Ahaz, in whose reign the sun-dial was constructed, lived until 728 B.C., and King Hezekiah, his son, reigned from 715 B.C. until 690 B.C. It is a matter of some regret that the form of the construction of the sun-dial was not recorded.

It is only fair, I think, to point out that devices⁽⁴⁾ have been constructed to demonstrate this apparent reversal of time. In other words, the whole affair would appear to have been a psychological device to aid the recovery of the King, and not a genuine reversal of time. As far as we are aware, from all our observations and our experience, time flows in one direction only. Since it is not possible at present to detect time reversal, the direction of flow must be an assumption only. Any event suffering a time reversal would be constrained within a closed loop and therefore continue *ad infinitum* without some external interference at the correct instant to re-open the loop, since all our observations indicate that only future events may be altered. To expand this theme would be highly interesting but would be purely speculative.

Let us, therefore, turn our attention to how man became aware of the concept of time and how this phenomenon, although its nature is completely unknown, may be measured sufficiently well to regulate the earthly affairs of men. Lover's trysts, mealtimes, rising and retiring to bed, battles, catching a train, *etc.*, all require some idea of the time. Nature in her all-seeing wisdom has fitted the higher forms of life with a biological clock,

generally with an approximately governed cycle corresponding to one revolution of the earth and known as the Circadian rhythm. In man this allows an approximate idea of the time but it may be modified to a large extent by immediate happenings. It has already been said that happiness or exciting happenings make time fly, conversely the opposite makes time seem endless. Again the Circadian rhythm can be seriously upset by the speed of modern travel in an east or west direction. The pattern of sleeping and waking may be seriously upset until adjustment is made and life returns to normal. Some biological clocks are very resistant to alteration, *e.g.* the succulent *Kleinia articulata* (Candle Plant) may be grown from seed in this country and behaves as any other normal plant in its first season of growth. After this it reverts to the growth pattern of the Southern hemisphere from whence it originates as a normal summer growing plant, it grows leaves and attempts to flower in our winter, *i.e.* it behaves as though it were still at home and makes no allowance for the change in environment.

Reverting to man, the record of his first ideas about time awareness and how to measure the passage of time has been completely lost in the mists of time itself. The pattern of behaviour resulting from the early sun rising to warm the earth, the need to look for food, the hot midday sun and the need to look for cooling shadow, the long evening shadows foretelling the approach of the dark night; was sufficient for many, many thousands of years. The effects of this long period are still with modern man, even without the assistance of some time measuring device the inner man alerts us to the need for sustenance *etc.* The longer rhythmic pattern of events corresponding to the seasons and the yearly journey of the earth around the sun must also have been realised by man in prehistoric times.

Approximately 6,000 years ago, in the valley of the Nile, a group of wandering people decided to settle by the fertile banks of the river. After a few hundred years a culture arose amongst these people that brought about many advances in human thought and knowledge. By 3,400 B.C. hieroglyphic writing had been evolved and great public works were being carried out. Religion was a very strong force in the lives of these people. Their priests not only looked after spiritual affairs but were also the intelligentsia. Astronomy was evolved and the knowledge gained was such that by about 3,300 B.C. the length of the year was estimated to be 365½ days, an error of less than one hour in five years!

It has often been said by historians that the cradle of civilisation is the area between the Rivers Euphrates and Tigris. Excavations show signs of

civilisations older by a thousand years or more than the Egyptian. A calendar based on the moon was evolved by these people; it is not surprising to learn it was attended with less success than a calendar based on the sun. The adoption of the moon as a time indicator was probably due to the shepherds tending flocks of sheep and goats and who learned how to interpret the rapidly changing appearance of the moon. Similarly other early civilisations developed calendars independently.⁽⁵⁾

These diversionary remarks have been brought in to show that if one is to look for the first beginnings of time appreciation, then the backward glance through time needs to be very long indeed. Written on clay and baked hard nearly 5,000 years ago are records made by men who lived in Ur, a city of Chaldea in the lower Euphrates valley. The reason these records are available to-day is due to a natural disaster in the form of a great flood which caused the inhabitants to abandon their city. These records indicate that they had visited Egypt and returned with the calendar originated by the priests. Their arrangement of small units of time differed from the Egyptian plan of one day divided into 10 hours, one hour divided into 100 minutes, and one minute divided into 100 seconds; (was this the first attempt at metrification ?), and the plan which is familiar to us was adopted, 24 hours in one day, 60 minutes in one hour, and 60 seconds in one minute. Only one unit was missing—the week, in addition their year had 12 months of 30 days with the five remaining days given actual names.

Moses in his flight from Egypt, about 1500 B.C., took with him the calendar he had been taught as a child but he modified it to suit the particular needs of the Israelites. Religion played a very important part in their new life and Moses wanted to make sure that the Sabbath was strictly observed. To ensure this he introduced a new unit of seven days so everyone would know when the Sabbath fell without having to be told by the priests. In the new system the religious festivals still had to be calculated by the religious authorities, the precise date of the festivals being dependent on the phase of the moon. Thus, for the first time, lunar and solar calendars were satisfactorily incorporated into one system for use in ordinary life. Each year had 52 weeks with a special day at the end of the year, or two in the case of a leap year. These days did not form part of a week, and months were not used as far as is known.

Julius Caesar took the next real step in resolving the conflicting requirements of the practical calendar. To do this he enlisted the aid of Sosigenes the foremost Egyptian astronomer. Basing his new calendar on the Egyptian model, Caesar took the remaining days at the end of the year

and distributed them among the months. He gave each odd month 31 days and each even month 30 days except for February which had 30 days in a leap year only. In addition he made the beginning of the year commence in January instead of March, one result of this was that the names of the months no longer denoted their position in the year correctly. For example September, or as the name denotes, the seventh month, became the ninth month and the name lost its earlier significance. The winter solstice of the year 46 B.C. was chosen for the start of the new style year and to achieve the correct starting point of the calendar, the year 46 B.C. had to have 455 days and was therefore called the "Year of Confusion"! Two years later Caesar was dead. To honour his name the Roman month of Quintilis was changed to Julius (July). His successor, Augustus, not to be outdone; also had a month named after him. Sextilis was chosen to become Augustus (August) but being an even month had the slight disadvantage of having 30 days only, hence it might have been thought inferior to Julius. An extra day was therefore taken from poor February.

Caesar's improvement of the calendar meant a difference of only 11 minutes and 11 seconds between the computed and astronomical year. One might be forgiven for thinking this to be of little account. After all there are 31,556,939·7 seconds in a year, so who cares about a mere 671 seconds too few per annum? From Moses to Caesar is an interval of 1,500 years, another 1,500 years after Caesar action was required again. By 1582 the accumulated error was such that the vernal equinox fell on the 11th of March instead of the correct date of the 21st of March. Pope Gregory II decided to make a correction by ordering that the 5th of October would become the 15th of October and so 10 days disappeared. To prevent a re-occurrence of such an error, Gregory decreed that three leap years would be omitted every 400 years, as a result the years 1700, 1800 and 1900 A.D. were not leap years but the year 2,000 A.D. will be. A small residual error remains so that in addition a leap year needs to be omitted once in every 4,000 years. Let us hope it is not forgotten in the distant future, assuming mankind is still in existence.

In England the learned Roger Bacon, English scientist and philosopher *circa* 1214 - 94, Doctor Admirabilis, had advocated a calendar reform three centuries before Gregory. Insular as always, not until 1752 did England adopt the Popish style calendar, meanwhile the error had increased slightly and the 3rd September, 1752, became the 14th September, thus striking out 11 days. The common herd did not care very much for this premature shortening of their miserable lives and

gathered in mobs to protest. One of Hogarth's engravings shows a large and excited crowd with a banner inscribed, "Give us back our Eleven Days". For a long time afterwards letters and legal documents bore two dates on them, one new style, one old style. The Act of Parliament reforming the calendar also stipulated the first day of January as the beginning of the new year instead of the 25th of March.

The procrastination in the reform of the calendar may seem undue even to those of us accustomed to the frustrating delays of the present system. The Gregorian adjustment resulted from a Church Council held at Trent in Italy to discuss the time of the spring equinox and the observance of Easter, a matter of some 1220 years after a meeting of the Church Council in the City of Nicaea in Asia Minor in 325 A.D. to discuss the self-same topic. It is interesting to note that a large part of the civilised world has no history for these missing days as a result of these calendar reforms; not everyone was upset however. Benjamin Franklin wrote in his Almanack, "Be not astonished, nor look with scorn, dear reader, at such a deduction of days, nor regret as for the loss of so much time, but take this for your consolation, that your expenses will appear lighter and your mind be more at ease. And what an indulgence is here for those who love their pillow to lie down in peace on the second of this month and not perhaps awake till the morning of the fourteenth."⁽⁶⁾

The Dawn of Time-Accrediation

So far, with the sole exception of the sun-dial of Ahaz, no mention of the means by which the passage of time has been, and is measured, has been made. The devices used, from the earliest days until the present date, will be reviewed in a chronological order as far as it is possible. They are important, not only from a time measurement point of view, but also because they occupied the minds of men possessing the highest intellects, initiated the need for astronomical research and scientific endeavour, laid the foundations of mechanical engineering, and made precision a meaningful word.

Before entering into an outline of the development of time measuring instruments, it will be convenient at this stage to review again the historical background. No doubt everyone at some occasion or another has heard the old cliche that time did not matter in the old days. Like all general statements made without due thought, this is only partially true. Consider one of our ancestors of the Stone Age engaged in mortal combat. On seeing a rapidly approaching club aimed at his head, he would most certainly have appreciated the difference between a near miss and a success-

ful contact with his cranium. A club with an approach velocity of 60 miles an hour (not unduly rapid) travels an inch in one millisecond. Similar conditions still apply to-day with the self-propelled clubs wielded by motorists approaching each other with the modest combined velocity of 60 miles an hour. Thus a millisecond may ultimately determine whether the participants will be in a position to abusively communicate later, less fortunately perhaps blame each other for expensive repair jobs, or more sadly, unable ever to communicate with anyone again. The passage of a few hundred thousands of years does not seem to have made any really radical change except in the choice of weapons.

Commencing the search for time appreciation in the Pleistocene era which was occupied by the single cultural period known as the Palaeolithic or Old Stone Age, nominally beginning about a million years ago, the first sign that can be positively identified is linked with the discovery of Pekin man. Originally named Sinanthropus by his discoverer, Professor David Black, who identified the ape-man of Pekin from a single tooth found at Choukoutien near Pekin, this near relation of modern man has left many traces of his existence of perhaps half a million years ago in the shaped stone tools and the charred bones of animals in the hearths constructed by him for cooking purposes. The use of such advanced techniques as the shaping of stone tools and the art of firemaking indicate a keen awareness of the future, i.e. a sense of time.

Another source indicating the thoughts and beliefs of mankind many thousands of years ago is found in the so-called cave paintings by men of the Upper Palaeolithic era in the Altamira, Lascaux, Le Roc, Tue d'Audubert, and other caves. Some of these paintings may be 20,000 years old and, although mainly concerned in depicting animals of the chase, demonstrate most adequately the quality of abstract thought of *Homo Sapiens* established in Western Europe some few tens of thousands of years ago.

The progress of man depends very largely upon his special ability to control his environment and a particular aspect of this is a specific knowledge of crop growing and the seasons. Permanent living sites are necessary for complex cultures to flourish and these can only be formed where adequate food and water supplies can be made available. We can only presume that the recognition of Nature's patterns grew over countless thousands of years of observations which indicated that agricultural operations had to be carried out at definite times corresponding to certain natural phenomena such as annual floods, positions of the

fixed and moving stars, the moon, and so on. Similarly the daily life of early man was obviously governed by darkness and daylight, the position of the sun in the sky, later perhaps by shadows of natural objects, and still later by shadows of sticks thrust into the ground; but this is only mere conjecture. It is not until around 1,500 B.C. that we find the first artefact for the measurement of time. This earliest known time measuring device is known as an Egyptian shadow clock and exists as a small fragment dated approximately at 1,500 B.C.⁽¹⁾ now reposing in the Neues Museum in Berlin. A similar clock of the tenth to the eighth century B.C. is shown in Fig. 1. A scale of temporal hours was used since dawn and dusk governed the life of most men until the advent of artificial illumination. The number of divisions was six, and at noon the device had to be reversed.



FIG. 1. Egyptian Shadow-Clock,
10th Century B.C.
(Science Museum).

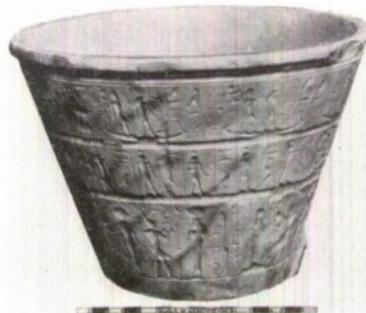


FIG. 2. Egyptian Water-Clock
from Karnak Temple, 1400 B.C.
(Science Museum).

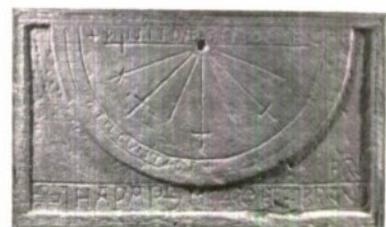


FIG. 3. Saxon Sun-Dial on
Kirkdale Church, A.D. 1060
(Science Museum).

Early Time Measurement Devices

Later the sun-shadow idea was developed into larger shadow clocks which utilised a shadow from a wall or pillar falling on to a flight of steps. Several versions of this type of sun-dial have been found during excavations in Egypt. Astronomers in Egypt devised the first method of finding the time during the hours of darkness by the use of two plumb lines to observe the transit of selected stars, dividing the combined day and night period into 24 hours of equal duration. Clepsydrae or water-clocks were developed from about the fifteenth century B.C. in order to meet the demand for a more convenient method of timekeeping during darkness (Fig. 2). Such ideas spread slowly throughout the civilised areas of the world, notably Greece and Italy, and were developed quite independently. Some measure of the progress made can be gained from the fact that the first sun-dial did not appear in Rome until 290 B.C., having been brought there as a trophy of war from Egypt; yet Vitruvius writing in 30 B.C. describes

no less than 13 different types. Sun-dials rapidly became common soon after the first introduction, so much so that Plautus⁽⁸⁾, the Roman writer circa 251 - 184 B.C., in one of his comedies makes a social parasite declaim against them as follows:

*"The gods confound the man who first found
out
How to distinguish hours! Confound them
too,
Who in this place set up a sun-dial,
To cut and hack my days so wretchedly
Into small portions! When I was a boy
My belly was my sun-dial; one more sure,
Truer and exact than any of them.
This dial told me when 'twas proper time
To go to dinner (when I had aught to eat),
But now-a-days, when—even if I have—
I can't tell to unless the sun give me leave,*

*The town's so full of these confounded dials
The greatest part of its inhabitants,
Shrunk up with hunger, creep along the
streets."*

Which is obviously one of the first plaintive cries against the domination of man by a device of his own making. However, as even the best of sun-dials cannot perform in the absence of the sun, clepsydrae were developed still further to cope with the measuring of time during cloudy days. Eventually they were to become so complicated as to include types that would play flutes or organs, or the sounding of bells at prescribed times.

In the British Isles there appears little evidence of time-keeping until the Romans brought with them the sun-dials with which they were familiar. A few of these have been unearthed during excavations, probably thrown away in disgust during the British summer by their Roman owners! Probably as a result of the long period of occupation by the Romans, the later Anglo-Saxons developed

their own sun-dials, the earliest one known being that of Bewcastle Cross, Cumberland, dated A.D. 670. Kirkdale Church has a particularly fine example dated A.D. 1060, *i.e.* just before the Norman invasion, shown in Fig. 3. The day was generally divided into four equal parts called tides and we still speak of eventide. After the Norman invasion of England, a more primitive type of sun-dial appeared. It may still be found on churches to-day and simply consists of a few lines which are thought to indicate the times of services in early days. These primitive sun-dials are called scratch dials. Mention must also be made of the method used by King Alfred the Great who made use of candles burning in a horn lantern to measure out his day's work. This fact is related by Asser, his biographer. Why he used this method when the Saxons were very familiar with the sinking-bowl type of clepsydrae, is not at all clear. The Saxon water-clocks were generally in the form of a bronze bowl with a small hole in the bottom, placed on the surface of water they slowly filled and eventually sank, indicating an elapsed period of time. Strange as it may seem, the sinking-bowl method is still in use to-day in some Eastern countries, mainly for determining the period of time allotted for the supply of irrigation water.

About A.D. 1500 interest revived in sun-dials and they were developed along scientific lines. The study of sun-dials, otherwise known as *gnomonics*, became quite an important subject, many books were written as a result and they make interesting reading to-day. Another time keeping device of the Middle Ages which is often met with even to-day, is the humble sand-glass. See Fig. 4 for a ship's four-hour type of sand-glass of the late 18th century. At one time sand-glasses were thought to have been evolved in Alexandria *circa* 150 B.C., a view now discounted. Sand-glasses are rather more difficult to make than one would imagine, and the preparation of the so-called sand⁽⁹⁾ was a closely guarded secret. It was generally made from pulverized egg shells and required many purifying and sieving operations to ensure constancy of action. Sand-glasses were extensively used by the Royal Navy for navigational purposes until quite late in naval history. How seamen undertook long sea journeys or even circumnavigated the globe with the help, or otherwise, of such primitive devices is beyond comprehension. Unfortunately space does not permit further discussion of the early methods of timekeeping, nor details of developments in other parts of the world, notably China.

Mechanical Timekeepers

Whilst some of the very early complicated water clocks of two thousand years ago incorporated

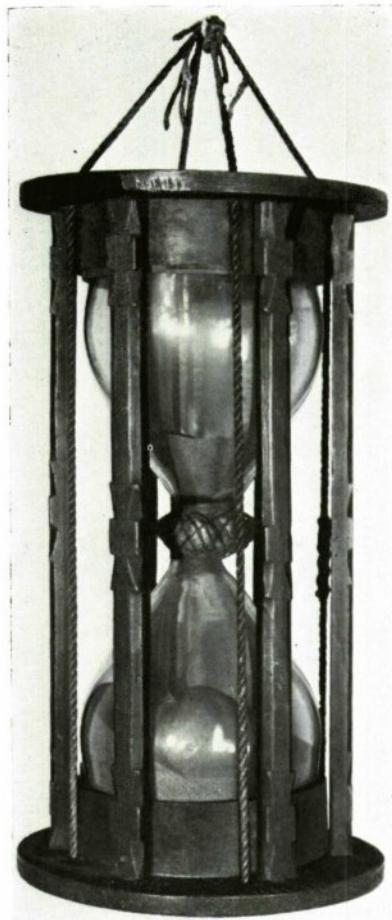


FIG. 4. Ship's 4-hour Sand-Glass, Eighteenth Century (Science Museum).

gear wheels and other mechanical details, the actual measurement of time was not achieved by mechanical methods until over a thousand years later. The earliest example extant of a mechanism involving the use of gear wheels is a small machine for showing the motions of the planets and the rising and setting of the stars⁽¹⁰⁾. By a good stroke of fortune it was recovered from a sunken treasure ship off the island of Antikythera, between Greece and Crete. Ancient Greek inscriptions upon it indicate the probable time of its making to lie somewhere between the first century B.C. and the first century A.D. Corroded fragments of gears, pinions, eccentrics, worms, annular gears, and concentric rings may still be identified in this marvellous specimen of ancient craftsmanship, even after 2,000 years of immersion in the sea. References in ancient literature indicate that Archimedes made a mechanical contrivance which showed the paths of the stars and planets; Cicero claimed to have seen this working. Although Archi-

medes lived in the third century B.C., is it possible that the Antikythera device was his?

These early references in literature, and the complexity of this early mechanical marvel, show that such work must have been carried out for many years, therefore it was not the lack of mechanical knowledge that prevented mechanical time-keepers from being made. The chief obstacle was the lack of a suitable device to control the motion of a weight driven gear train. When or how this was first achieved is not known; the name of the genius who first solved the problem is now completely lost to us. The earliest European regulating device for mechanical clocks known is the verge escapement. This step by step regulating device may have developed from the much earlier bell ringing mechanisms, however the earliest step by step release of a train of wheels in a clock was used in the Chinese Su Sung water driven mechanical clock of A.D. 1088, known only from its description by contemporary writers, as the clock itself has long since disappeared. From a translation of the description of the clock in print in A.D. 1172, it has been possible to construct a working model which may be seen in the Science Museum, South Kensington. The original clock, a complicated astronomical type, was housed in a tower 37 ft in height.

Various dates for the first mechanical time-keeper have been given, starting with the clock of Pacificus, Archdeacon of Verona, who died A.D. 849. Another claim is that of Gerbert's clock constructed at Magdeburg in the tenth century. It is extremely difficult to ascertain the truth of these details for it was the custom in those early days to refer to all time measuring devices as 'horologium' regardless of type. In England the first mechanical clock appears to be the one erected in 1298 in the Palace Yard opposite Westminster Hall, the cost being defrayed from the fine imposed on the Chief Justice of the King's Bench, supposedly for having the court records altered in order to reduce the amount of a fine imposed on an impoverished prisoner. No details of the clock mechanism now exist.

Many authorities aver that mechanical clocks were first made in Italy or France. A large public clock was set up in Milan in 1335, and a much more complicated clock was erected at Rouen in 1389. It chimes the quarter hour and strikes the hour to this very day, although many parts have necessarily been renewed. At Salisbury Cathedral the oldest working clock in the world may be seen functioning (Fig. 5); it dates from about 1386. Like many of the early clocks, the Salisbury clock possesses no dial—the time is indicated by the striking of a bell. These early clocks are massive iron structures, which when originally made

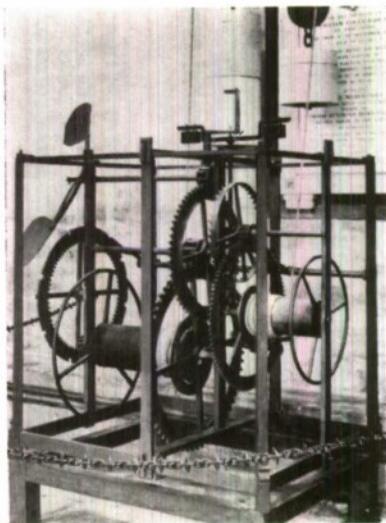


FIG. 5. Salisbury Cathedral Clock, A.D. 1386.

required the skill of expert blacksmiths. Accounts of the making of these clocks show a real understanding of critical path methods and the techniques of team working. A great feature of the construction and repair of early clocks was the provision of ale, or wine, and food; whilst the conclusion of the work and the successful commissioning of the clock was often marked with a celebration feast.

Giovanni De' Dondi (1318 - 1389) Professor of Medicine, Logic and Astronomy at both Florence and Padua, not only constructed in 1364 a most marvellous astronomical clock completely in brass, but also left a complete description in Latin under the title "Tractatus Astrorii", and a second description after some small alterations to his clock, called "Opus Planetarium". A copy of the latter in the Bodleian Library, Oxford was translated into English some years ago and from this an exact replica of the clock was made which now repose in the Smithsonian Institute in Washington D.C. Some idea of the advanced design may be gained from the following details. Provision was made for the effect of the slightly elliptical orbit of the moon, recording of minutes, not repeated by anyone else for 200 years, and a perpetual calendar for Easter which was not repeated by any other clock-maker for 500 years! Three more copies are to be made for various scientific bodies in different parts of the world. Incidentally De' Dondi stated that as the time measuring part of his weight-driven clock was of a type familiar to clockmakers, it would be unnecessary to describe it in the same detail as the complex astronomical motions. No words of the writer can even remotely convey the sheer genius of Giovanni De' Dondi's astronomical clock.

Early Domestic Clocks

Domestic clocks began to appear in the early part of the fifteenth century, mainly in Germany and Italy, and were constructed completely of iron. Quite often the time indication was given by a moving dial and fixed pointer. With the invention of the spring, formed from a long ribbon of steel shaped into a coil, portable table clocks were made for the first time. In England such clocks began to be made towards the end of the sixteenth century. After a short period of production of clocks in the continental style, a characteristically English clock appeared and became known as the *Lantern* clock. It was fitted with the verge escapement driving a foliot or balance. Adjustment to the timekeeping was made by alteration of the driving weight through the addition or subtraction of lead pellets, necessary since the controlling device used had no natural period of oscillation.

Galileo Galilei first discovered the isochronous properties of the pendulum although neither he nor his son Vincenzo completed a successful clock. The first pendulum clock was produced by Christiaan Huygens (1629 - 1695) in 1657. The speed with which the new invention was introduced seems almost fantastic, for in 1658 the first pendulum clocks in England were made by Fromanteel. His advertisement in the *Mercurius Politicus* for 27th October, 1658, reads: "There is lately a way found out for making clocks that go exact and keep equaller time than any now made . . . and may be made to go a week, a month, or a year, with one winding up . . . Made by Ahasuerus Fromanteel, who made the first that were in England . . ." The golden age of clockmaking had begun in England; not only did the new pendulum clocks tell the time much more accurately but the cases housing them became minor works of art.

Short pendulums were employed in the earliest pendulum clocks as the escapement used was still the verge and the resulting arc of the pendulum was very large, thus necessitating a short light pendulum. An ingenious method of Huygens, incorporating a reduction gear between the verge and the pendulum, allowed the use of a much longer and heavier pendulum; however it was not successful. A new escapement called the *anchor* was invented in England about 1670. Two men laid claim to the invention, namely William Clement and Robert Hooke. Needing only a small arc for operation, and allowing the use of a long pendulum and a heavy bob, adoption of the anchor escapement revolutionised timekeeping, reducing the daily error to a few seconds in clocks so fitted. Strangely enough the new pendulum clocks were often supplied with sun-dials, for it must be realised that no time distribution service existed

then. By means of a sun-dial and an *equation of time table*, a clock could be corrected to local time.



FIG. 6. Regulator Clock
with Mercury Compensated
Pendulum.

Precision Mechanical Clocks

Already the common pendulum clock had reached precision within approximately 0·005% (300 years ago!). Whilst such accuracy would seem adequate, it was soon found that variations of temperature altered the rate of the clock by one second a day for a change of 4°F in the case of a pendulum fitted with an iron rod. George Graham and John Harrison independently found the remedy for these temperature errors, their compensated pendulums being invented about 1726. Additionally Graham had invented a variation of the anchor escapement called the deadbeat which interfered less with the pendulum's motion. Clocks employing the dead-beat escapement and mercury compensated pendulum became the standard time-keepers for almost 200 years, having an error of

one or two seconds a week, or about 0·001%. English horologists entered a long period of unchallenged supremacy during which they became complacent. Ultimately, when faced with external competition, they were unable to respond.

For the utmost precision in timekeeping a special type of clock was evolved called the regulator clock, Fig. 6. In these clocks everything was directed towards perfection in timekeeping, mainly by perfection in the gear train to ensure absolute constancy of impulse to the pendulum. Eventually Riefler in Germany perfected this type and reduced the daily error to a mere 0·01 second. England lost its lead in precision timekeeping for the first time in over two hundred years, but this was restored through the invention of the 'Free Pendulum'⁽¹¹⁾ by W. H. Shortt, a railway engineer, in 1921, Fig. 7. Variations in timekeeping were reduced to one or two thousandths of a second a day. Development of the pendulum clock as a precision timekeeper came to an end with this invention.

Later Domestic Clocks

In domestic clocks where timekeeping to a minute or so a week was deemed adequate, the emphasis lay more in artistic appeal and the provision of auxiliaries such as calendar indication, phase of the moon indication, and repeat striking mechanism which allowed the time to be ascertained during the hours of darkness. Early clocks were carried from one room to another as they were so expensive that only one would be owned. Because the verge escapement was less critical in operation than the later escapements, it continued in use long after the invention of the anchor escapement. Musical clocks in ornate cases became very popular in the eighteenth century. Clocks in this type of case are known as bracket or table clocks. Domestic clocks later became available in an infinite variety of styles, low cost became the criterion, and they were rarely fitted with precise escapements since an accuracy of one minute or so a week is sufficient for the ordinary way of life. Domestic timekeeping today is generally of a lower order of accuracy than before the last war due to the adoption of synchronous electric clocks whose accuracy depends on the frequency of the mains supply. Electrical load-shedding leads to a reduced frequency, hence the clocks go slower, a loss made good during periods of light loading, hence an accumulated error does not arise. Before the last war electrical supply companies were under a legal obligation to maintain the supply frequency within certain limits. At present it is impossible to do this at times of peak demand.

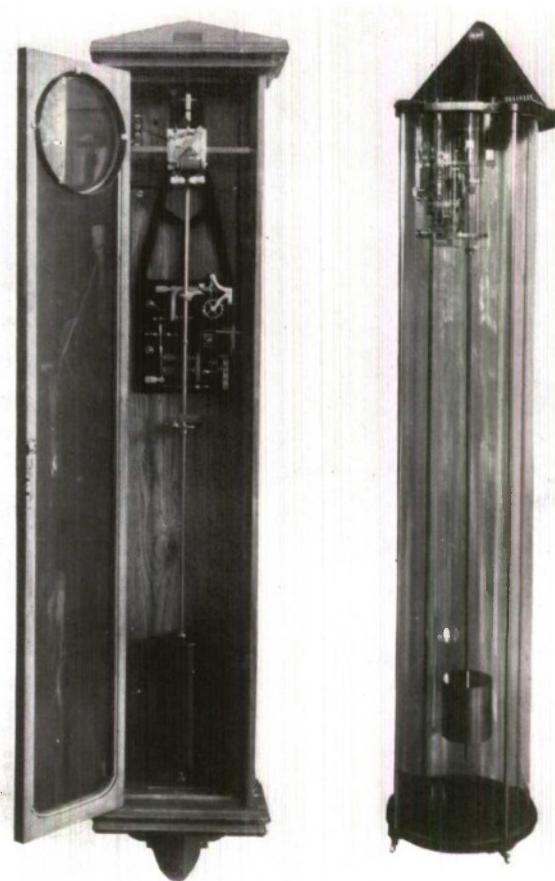


FIG. 7. Free Pendulum Clock with Slave Clock (Science Museum).

The Quartz Crystal Clock

With the development of stable frequency oscillators using quartz crystals for radio communications, attention was directed towards their use for time measurement. W. A. Garrison of the Bell Telephone Laboratories was the first to use quartz crystal oscillators⁽¹²⁾ to measure time precisely *circa* 1927. L. Essen of the National Physical Laboratory designed the quartz ring oscillator in 1938⁽¹³⁾ and it became the primary standard for timekeeping in many observatories, ousting the free pendulum and other clocks. A great advantage of the quartz crystal clock is the ability continuously to compare its rate against that of other quartz crystal clocks. Electrical circuits divide the high frequency oscillation of the quartz crystal to a frequency suitable for driving a small synchronous electric motor. Unlike a pendulum clock, time is continuously indicated by the quartz crystal clock. The pendulum regulator clock usually advances the indication in increments of one second, or as in the case of the free pen-

dulum, in increments of half a minute. Time measurement by mechanical clocks can hardly be considered continuous and the actual indication is always in error. Fig. 8 shows an early type of quartz crystal clock⁽¹⁴⁾, several decades of considerable development has enabled the size to be reduced to the extent of enabling a quartz crystal wrist watch to be demonstrated recently and it will be on sale in 1970⁽¹⁵⁾.

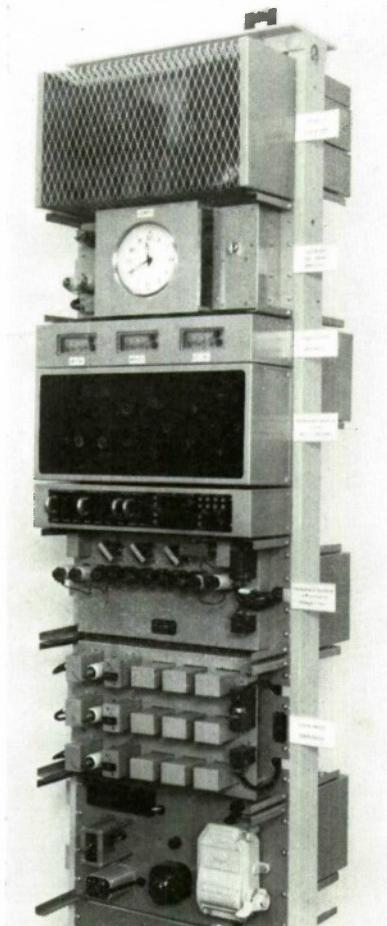


FIG. 8. Early Type of Quartz Crystal Clock (Science Museum).

The Atomic Clock

There are a number of different types of atomic clocks, of which the caesium atomic clock is one. An early model is shown in Fig. 9. For many years it was suspected that the earth was subjected to variations in the time of rotation, proof of which was finally achieved by the use of the free pendulum clock. A search was instituted for a more fundamental standard that would be independent of outside influences. Such a standard was invented by the U.S. Bureau of Standards who made use of the ammonia molecule as a reference standard⁽¹⁶⁾. However the accuracy proved to be

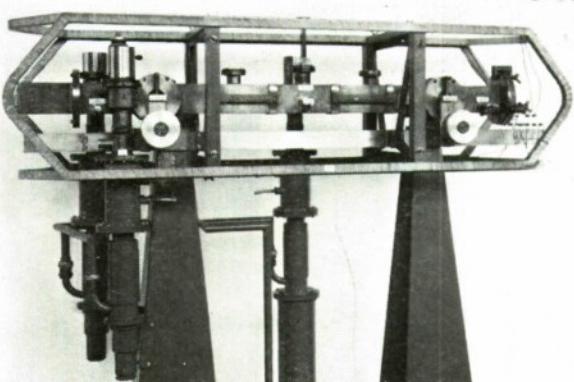


FIG. 9. Caesium Atomic Clock (Science Museum).

little better than the quartz crystal oscillator. Dr. L. Essen and Mr. Parry of the National Physical Laboratory later made use of the caesium atom as a standard⁽¹⁶⁾, in the mode of oscillation used, the resonant frequency being 9,192,631,804 Hz, the resulting accuracy of clocks using the caesium atom as a standard is presently of the order of *one second in three thousand years*. Other atomic standards are currently in use for portable time-keeping standards. A typical commercial model is shown in Fig. 10.

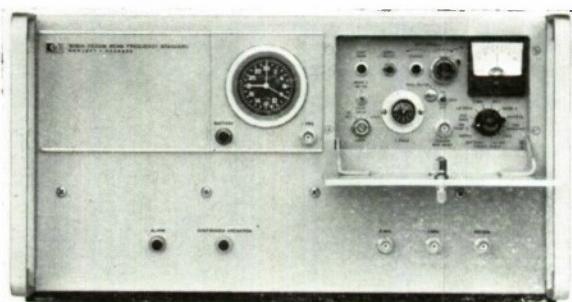


FIG. 10. Portable Time-Standard Equipment (Hewlett-Packard).

Progress Review

Before closing a brief glimpse into the long history of practical time measurement, the accuracy of time measurement expressed in linear terms may be of interest.

Supposing someone asked you to pace out a distance of exactly 16 miles 640 yards 0 inches. At the end of your journey you might imagine your accuracy to be extremely high if you were informed that a mere three yards separated you from the correct finishing point. Perhaps you would be more concerned with your blisters and aching feet. Apply the same proportion of error to a timekeeper and there would be a daily error of nine seconds, i.e. the performance of a relatively cheap wrist watch

strapped to someone's wrist and subjected to many sudden disturbing motions and random changes of temperature during the twenty-four hours taken by the earth to turn through one revolution. The error is approximately one part in 10^4 or 0·01%.

By the end of the evolution of mechanical precision timekeeping, culminating in the invention of the free pendulum clock, the error had been reduced to a mere one millisecond or so a day, corresponding to pacing out the previous journey to within twelve thousandths of an inch, an error of about one part in 10^8 . Since the most precise astronomical measurement of time obtained by averaging out a series of successive transits of a star across the meridian gives the length of the sidereal day to within approximately 0·01 second, and the rotation of the earth shows irregularities of about seven parts in 10^8 , the achievement of past clockmakers is something to be marvelled at even in this age of miracles. Yet the precision timekeeping of the world has not been measured by mechanical clocks for a good many years, the simple reason being that their daily error is much too large to meet the insatiable requirement for accuracy of time measurement demanded by science today.

After only ten years of supremacy by the electrically driven free pendulum clock, the invention and development of the quartz crystal clock rendered the groping efforts of centuries completely obsolete for precision timekeeping purposes. An error of a few parts in 10^{10} in the rate of a crystal clock⁽¹⁷⁾ has been reached after several decades of development. In turn the crystal has been relegated to the position of a subsidiary time standard by the atomic clock which possesses an error of one part in 10^{11} or less. Expressed in terms of our imaginary journey this would mean an error of only ten millionths of an inch. On a topical theme the equivalent error in measuring the distance from the earth to the moon would be about four millimetres! Thus the atomic clock would have to run for thirty thousand years before accumulating the error of our wrist watch gained in a single day!

Conclusion

To those readers who have found this article somewhat disjointed and lacking in finer detail, apologies are expressed. The history of time is as old as time itself and therefore a vast subject not easily compressed into a few words. And as with all historical accounts, the same facts are repeated, the best that can be done is to present a fresh point of view if this is at all possible. The present is made up of small pieces of the past and until the nature of time is resolved unknown worlds and knowledge will remain hidden from us. Is

time really the imponderable quantity that it has seemed to every individual member of the human race who has existed up to now?

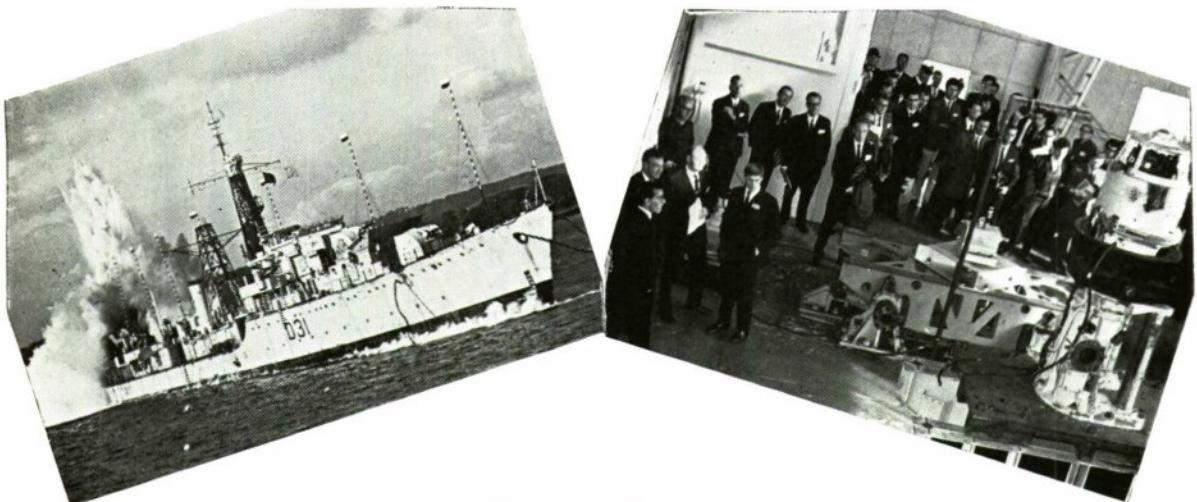
Finally, it is appreciated that there are many gaps in this article, in particular the naval aspect of time measurement has not been developed, a deliberate omission, for the subject is deserving of more than a passing mention. The infinitely more difficult task of time measurement at sea seemed incapable of solution up to two hundred years ago. Many brilliant men failed to find the answer and even Sir Isaac Newton had doubts as to whether a device could be constructed for measuring time at sea. Therefore the writer was forced to the conclusion that in order to do justice to the important subject of time measurement at sea, a separate article would be necessary. This present article will provide the background for the next, for, as in so many cases, the problem which is easily resolved in a stable environment on land takes on a new dimension with the unstable environment found on the surface of the sea.

Acknowledgement

Mrs. B. Edwards, N.S.T.I.C. for obtaining references.

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- (14) "A Quartz Clock." C. F. Booth. *P.O. Elect. Eng. J.*, Part 2, **39**, 33 ff.
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Open Days

Naval Construction Research Establishment

The Naval Construction Research Establishment held its first ever "Open Days" from 23rd - 27th September, 1969. Over 1,000 visitors from Industry, Universities, Research Establishments, Ministry of Defence and Ministry of Technology, Technical Colleges and Schools took the opportunity to view the many activities of the Establishment. The work of N.C.R.E. has been reviewed recently in the previous issue of the Journal and much of this work was on display. A general coverage of N.C.R.E. projects was achieved by the use of display stands which were sited in the various Divisions throughout the Establishment. Technical briefs on all the major items of work in the Divisions were also provided for visitors.

At the St. Leonards half of the Establishment, visitors were able to see a film portraying aspects of N.C.R.E.'s work which could not be put on display. Parts of St. Leonards which were open to visitors included the Low and High Pressure Chambers, the Stress Analysis Laboratory, the Computer and Data Links and the Instrumentation and Metallurgy Laboratories.

At the South Arm site in Rosyth Dockyard the Noise and Vibration Laboratory gave a demonstration of the vibration reducing characteristics of the shock mounts developed by N.C.R.E. The Mechanical Testing Laboratory conducted demonstrations of a spectacular wide plate test, and fatigue machines could be inspected whilst in operation. The Welding Development Division displayed various modern welding techniques and methods of non-destructive testing, including an ultrasonic immersion tank in action to automatically scan plates for weld defects. The Large Test Frame facility was on view and visitors were also shown parts of a one-eighth scale model of the centre section of a Supertanker being fabricated in the workshops for future testing in the Frame. The Submarine and Surface Ship Divisions had several models on show, but of particular interest, was a two-third scale centre section of a proposed Glass Reinforced Plastic Minesweeper design, through which visitors could walk. The Explosion and Shock Divisions had also set up several demonstrations including small charges fired underwater against simple submarine models in an explosion tank, in order to demonstrate the effect of depth of water on explosion damage. A film demonstrating the behaviour of underwater explosion gas bubbles in the vicinity of the water surface and structural targets was also shown as well as a shock machine demonstrating the shock testing of ship equipment and machinery.

The 24th September was set aside for 40 representatives of the Press and TV. On this occasion Mr. K. G. Evans, M.R.I.N.A., R.C.N.C., Superintendent, Mr. I. J. Campbell, M.A., R.N.S.S., Chief Scientist, and senior members of the staff led the visitors on a conducted tour of the Establishment. A Press Conference was later held, during which the Superintendent explained how the Establishment's experience and knowledge of the design of large structures and of the applications of high strength steels and new materials, which had been gained in research on warship design, were now being made available to Industry. The final day was a special occasion reserved for relatives and friends of the staff. For the first time, they were able to see the Establishment for themselves and obtain a personal impression of its varied activities. As a result of the sterling efforts of all R.N.S.S., R.C.N.C. and supporting staff the N.C.R.E. Open Days were an outstanding success.



BOOKS RECEIVED FOR REVIEW

Offers to review should be addressed to the Editor

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|--|---|
| Examples in Engineering Science. First Year T1.
Hurlow and Lake.
Blackie and Son Ltd. 1969. 11s. (No. 1755). | Reactions in Carbonyl Compounds.
F. D. Gunstone.
English Universities Press. 1969. 11s. (No. 1763). |
| Examples in Engineering Science. Second Year T2.
Hurlow and Lake.
Blackie and Son Ltd., 1969. 11s. (No. 1756). | Analysis of Surge.
John Pickford.
Macmillan and Co. Ltd. 1969. 55s. (No. 1764). |
| Data Processing.
K. N. Dodd.
English Universities Press. 1969. 11s. (No. 1757). | Coastal Hydraulics.
A. M. Muir Wood.
Macmillan and Co. Ltd. 1969. 55s. (No. 1765). |
| Nature Science Report 1970.
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W. M. Brown and Carmen J. Palermo.
McGraw Hill and Co. Ltd. 1969. 149s.
(No. 1766). |
| Microbial Contamination Control Facilities.
Edited by R. S. Runkell.
D. van Nostrand. 1969. 112s. (No. 1759). | Elements of Advanced Quantum Theory.
J. M. Ziman.
Cambridge University Press. 1969. 55s.
(No. 1767). |
| Electrical Instruments and Measurements.
Kidwell.
McGraw Hill Ltd. 1969. 105s. (No. 1760). | Welding Handbook.
6th Edition.
Macmillan and Co. Ltd. 1969. 120s. (No. 1768). |
| Energy and Bonding.
M. Hudson.
English Universities Press. 1969. 21s. (No. 1761). | Matrix Analysis of Discontinuous Control Systems.
P. V. Bromberg.
Macdonald. 1969. 100s. (No. 1769). |
| Applied Heat for Engineers.
J. B. O. Sneeden and S. V. Kerr.
Blackie and Son Ltd. 1969. 38s. (No. 1762). | |

Retirements

J. RIGBY, M.I.E.E., C.Eng., R.N.S.S.

John Rigby retired from the Admiralty Compass Observatory on 17th October, 1969, having served at Ditton Park for over 30 years.

A native of Lancashire, he received his early training in electrical engineering in the north west, where, after apprenticeship, he became concerned with electrical equipment in the coal mining industry. In 1926 he joined Metropolitan Vickers of Manchester, where he was engaged in the design of large electrical machines for steel workers, carrying on this class of work subsequently with H. A. Brassert Limited, Steelworks Consultants, in London.



He became a Graduate of the Institute of Electrical Engineers in 1927 and was elected a Corporate Member in 1943.

Joining the A.C.O. shortly before the second world war, he was initially engaged in supervising the inspection of compass and associated equipment at manufacturers' works, later being appointed Chief Inspector of Magnetic Compasses.

After the war, he spent some time on the development and trial of navy and army distant-reading magnetic compasses, then joined the section dealing with gyro compasses and gyros.

Here he was principally associated with transmitting gyro/magnetic compasses and the gyros by means of which later versions of this type of equipment are stabilised. Later, he dealt principally with compass problems from sea service.

Since 1963 Mr. Rigby has been Technical Assistant to the Chief Scientist, in which capacity he was engaged in administrative, training and personnel management duties.

John Rigby has achieved considerable local eminence outside his Service duties at A.C.O. He was elected a member of Slough Corporation in 1951. He became an Alderman in 1967 and was elected Mayor of the Borough for the 1968/69 period.

At a farewell presentation, the Director, Captain T. D. Ross, R.N., handed over a cheque as a token of esteem from Mr. Rigby's many friends and colleagues, expressing great appreciation not only for Mr. Rigby's services to the Navy Department but also for the reflected glory A.C.O. had derived from such an eminent citizen.

Mr. Rigby thanked the assembled company for their gift and told of his less salubrious places of work in northern latitudes, underlining his good fortune in discovering A.C.O. where he was happy to have remained for so long.

John Rigby has been a friend, helper and adviser to all who were associated with him or cared to approach him, and although he will be missed greatly, A.C.O.'s loss will doubtless be others' gain. All John's friends and colleagues wish him and Mrs. Rigby every happiness for the future.



F. F. BUTTERWORTH M.Sc., Ph.D., F.I.Mech.E., R.N.S.S.

Fred Butterworth retired from the R.N.S.S. on 30th September 1969, after 22½ years' service.

Born in May 1904 he commenced his working life as an apprentice in 1920 with T. Robinson & Sons, machine tool makers. This was followed by 3½ years as machine shop foreman with the same firm. During this period of his working life he attended evening classes at Manchester College of Technology where he obtained his H.N.C.

In 1929 he embarked on full-time study at Manchester University taking a B.Sc.(Tech.) with First Class Honours immediately followed by M.Sc. and Ph.D. on research in internal combustion engines.



In 1935 at the end of this intense period of study Fred Butterworth joined Ricardo & Co. at Shoreham by Sea where he carried out internal combustion engine research.

At the outbreak of World War II Ricardo & Co. was transferred for security reasons to Oxford and Fred Butterworth continued his work there until December 1942.

He was then loaned to the Admiralty to develop a depth/time fuze for use in a new ahead thrown anti-submarine weapon which was being developed by the Mine Design Department at Havant.

In the post war reconstruction he was appointed to the R.N.S.S. as an S.S.O. but within a very short time was promoted, finally to a D.C.S.O. in 1960 when he became Head of the Weapons Department at A.U.W.E. Portland.

Fred Butterworth continued to work in the anti-submarine weapon field and he showed himself to be a very competent and clear thinking engineer with a full appreciation of the problems relating to anti-submarine warfare. He was awarded the O.B.E. in the 1957 New Year's Honours list for his services in this field.

Apart from his specialisation Fred Butterworth had a wide interest and knowledge of technical subjects and was always ready to help staff with their technical problems.

We wish him and Mrs. Butterworth every happiness in a well earned retirement.

The picture shows the Director, Dr. R. Benjamin (left) making a retirement presentation to Dr. Butterworth.



J. NORRIS, R.N.S.S.

John Norris retired from the R.N.S.S. on 31st August, 1969 after a long career in the service, most of which was devoted to information work.



After serving in R.E.M.E. during World War II he joined A.S.E. as a temporary draughtsman in October 1945, later transferring to the Assistant grade. In January 1946 he transferred to A.G.E. Teddington as an Experimental Officer, and moved into the information field. When A.G.E. moved into new premises at Portland in March 1954,

John transferred to Portland to set up and take charge of the Information Centre. After many months of planning, which had begun long before the move to Portland, the organisation and system of information handling at A.G.E. was inaugurated, and it is still in use today in A.U.W.E. with only minor modifications.

Promotion to S.E.O. came in July 1960, after A.G.E. had become Underwater Weapons Establishment with the beginning of the "Way Ahead" concentration of underwater R. & D. at Portland and, when H.M.U.D.E. was amalgamated with A.U.W.E. in September 1960, John took charge of the combined U.W.E./U.D.E. information centres.

In private life a keen photographer and gardener and a confirmed "do-it-yourself" addict, he will still find spare time all too short, even in retirement, but to ease the burden somewhat, his colleagues subscribed to a collection of power tools with which to speed his do-it-yourself activities, and the photograph shows Mr. V. H. Taylor, Assistant Director, A.U.W.E., formally presenting his colleagues' cheque on John's last day in the establishment.



J. J. YOUNG, R.N.S.S.

Josiah J. Young, 'Joe' to his many friends and acquaintances, retired on 31st October, 1969 after spending almost the whole of his working life in Admiralty Service.

He joined as an Apprentice at Chatham Dockyard in 1921, and after promotion to the drawing office, (and a brief flirtation with life outside the service) he was transferred to the Department of Torpedo and Mines at Whitehall. Here he joined a Section concerned with the design and development of torpedo control and gun direction equipment. During these formative years at the drawing board he was fortunate to work under the direction of several outstanding designers, notably Mr. H. H. Clausen, and contributed to the design of the open sights and analogue computers of the period, most of which saw satisfactory war service and some many years of post-war service. The Cruiser 'B' Sight, The Submarine Torpedo Director (The Fruit-Machine) and the 'M' Sight, which was developed at the suggestion of Cdr. (later Earl) Mountbatten and installed in the old *Tribal* Class Destroyers, were all instruments of this epoch.

During the war the Fire Control Sections of the Department of Torpedo and Mines were assimilated into the Directorates of Naval Ordnance and Electrical Engineering, and Young moved to Bath with the evacuation and served as

First Class Draughtsman in a Section headed by Mr. H. S. Miles. This Section was responsible for all aspects of Naval Ordnance Fire Control which could not be classified as Low Angle Gunnery or Long and Short Range High Angle Gunnery. Inevitably the Section became known as the Miscellaneous Section and the miscellany included Submarine and Surface Ship Torpedo Control, Target Indication, Wind Gear, and later, the stabilisation equipment for Hedgehog and Squid. During this period Young specialised in Target Indication and by dint of hard work was instrumental in the introduction of Pelorus and Sided Sights, Air look-out Sights, Universal Mag-slip Sights, Target Indication Units and did much of the work associated with the complex task of adapting existing British Equipment to the U.S. Mk. 37 Director-Computer system when it was introduced into the R.N.

He was promoted to Technical Officer in 1944, and on formation of the R.N.S.S. in 1946 was appointed S.E.O.

When D.N.O. reorganised his Department so that all R. & D. was accommodated in the Admiralty Gunnery Establishment, Young moved with the Section to Teddington and later to Portland. He retained his interest in Target Indication but now returned to his original vocation and in the face of constantly changing requirements led the U.C.S.F. (Torpedo Control Systems for Frigates) project.

In 1958 he moved with the Section to H.M.U.D.E. and on the formation of A.U.W.E. was transferred to the Torpedo Division. His responsibilities here were the design and operation of Torpedo Test Equipment and torpedo wiring, for his first few years he carried out this work almost entirely unaided. A lifetime of experience in electro-mechanical design stood him in good stead in this new task which occupied him up to the time of his retirement.

On his last day at work, Mr. Vic Taylor, his Division Leader at the time, made a presentation, in the presence of some of his friends and colleagues, of a Georgian Silver Bon-Bon Dish. In his address, Mr. Taylor remarked on Joe's extraordinary capacity for work, not only within the Establishment but also as his principal hobby, and on his shrewd sense of business which he has applied uncompromisingly to the betterment of his talented family.

All his friends wish him well in his retirement.

Notes and News

Admiralty Experiment Works

At the beginning of October Mr. C. B. Wills visited N.S.R.D.C. and Hydronautics in the U.S.A. to discuss propulsion devices and in particular tandem propellers. In November Mr. R. K. Burcher read a paper at the Second Ship Control Systems Symposium held by N.S.R.D.L., Annapolis, U.S.A. on "Progress on Manoeuvring at A.E.W.". Lectures were given at University College, London, by Messrs. J. E. Conolly, T. B. Booth and R. K. Burcher to members of the post-M.Sc. course.

The widening outside interest in A.E.W. activities is reflected in visits from the Institute of Electrical Engineers, Messrs. Dirkswager and J. de Jongh from Holland, representatives of the Norwegian Tanks and Research Institute, Esso, G.E.C., and the P. & O. Line.

In order to give A.E.W. staff a better knowledge of the work of the Establishment a series of weekly 'in house' lectures has been started and will continue until March 1970.



Admiralty Underwater Weapons Establishment

As part of the Exchange Scientist programme with the United States, Mr. R. M. Roberts, S.S.O., transferred to the U.S. Navy Underwater Sound Laboratory, New London, during October 1969, for a period of about two years. He is the first Exchange Scientist from A.U.W.E. to go to U.S.L.; previous exchanges have taken place largely with the Naval Undersea Research and Development Centre at San Diego, California.

Dr. W. A. Strawderman of the U.S. Navy Underwater Sound Laboratory, New London, has joined A.U.W.E. for one year, to work on theoretical aspects of sound and vibration. Dr. Strawderman has worked previously on flow and flow-induced noise, and has published papers in the Journal of the Acoustical Society of America.



Mr. R. J. Vachon, of N.U.R.D.C., Dan Diego, has joined A.U.W.E. for one year to work on the problems of beam forming and beam stabilisation with large planar arrays as part of the U.K. Aimed Sonar Research Programme. His previous work in the U.S.A. was also concerned with similar problems and with general test and evaluation of the U.S.N. conformal/planar array project.

Development of computer aids for design and engineering of underwater weapons is continuing. A paper was read by Mr. J. R. A. Jones at a conference on Programming Languages for Machine Tools organised by the International Federation for Information Processing in Rome during September. In October Messrs. C. J. Sharpe and A. E. Williams attended a conference on Numerically Controlled Machines at the Institution of Mechanical Engineers.

Four members of the staff of the Royal Military College of Science, Shrivenham, visited A.U.W.E. on 14th November for discussions with a view to including underwater weapons in their existing Guided Weapons Course.

Representatives of the Committee on Marine Technology visited A.U.W.E. on 6th and 7th November to survey the R. & D. programme to identify items which might have application outside the A.U.W.E. programme, in the general fields of oceanography and marine technology.



Naval Scientific and Technical Information Centre

Melvin S. Day, Deputy Assistant Administrator for Technology Utilization at the Headquarters of the National Aeronautics and Space Administration visited the Centre on 13th November, 1969 for general discussions on the exchange of information, and in particular in connection with the N.A.T.O. AGARD Technical Information Panel, of which both he and Head of N.S.T.I.C. are members. The six-monthly meeting of the Ministry of Defence (Navy Department), Information Officers was held at the Admiralty Marine Engineering Establishment on 12th November, 1969. A large number of Information Officers from various establishments and departments attended, and matters affecting the running and improvement of the information service were discussed. After lunch, the representatives were conducted over the establishment and senior officers explained the work being undertaken in the various sections. The next meeting will be held in the Spring of 1970 at the Admiralty Experimental Diving Unit by kind permission of the Officer in Charge. Mr. B. C. Dodge attended the B.S.I. sub-committee OC/20/8, Abbreviations and Codes in documentation, on 14th November, 1969 when the first proofs of the revised B.S.4148 were discussed.

Parties of Scientific and Experimental Class officers visited N.S.T.I.C. on 7th and 14th October as part of the programme of Newly Appointed Officers' Visits to Establishments. The talks on the work of the various sections of N.S.T.I.C., and the informal discussions which follow, give these new entrants a valuable insight into the resources of the Centre and the ways in which it can serve Navy Department Branches and Establishments.

Mr. J. C. Dunne, N.S.T.I.C., presented a lecture on "The Principle of Abstracting" to the Aslib Senior Introductory Course on Special Library and Information Work on 18th November, 1969. This two weeks' course provided a comprehensive introduction to the work of librarians and technical information officers, covering, as it does, a wide-range of topics.

On the 21st November, Mr. P. G. Williams, Reports Section, visited the National Lending Library for Science and Technology, at Boston Spa, Yorkshire. Mr. Williams' visit followed those by members of N.L.L. staff to N.S.T.I.C. These visits, and the ensuing discussions, have enabled N.S.T.I.C. to take the maximum advantage of the comprehensive and speedy service that N.L.L. provides in the areas of published literature and unlimited reports.



Services Electronics Research Laboratory

Mr. C. C. Pearce attended the Inter Nepcon '69 Brighton Conference and exhibition, concerning micro-electronic techniques and devices.

Dr. H. A. H. Boot and Messrs. M. J. Beasley, B. R. Holeman, R. G. F. Taylor and K. Trezise attended an I.E.E. meeting on 'Industrial and Medical Applications of Infrared Thermal Imaging Techniques' in London on October 23rd.

Messrs. B. R. Holeman, R. G. F. Taylor and G. P. Wright visited France from 26th to 30th October to attend a meeting of the Special Devices Sub-Group of the Anglo-French Collaboration on Valves and Semiconductors. They also visited a number of French research laboratories at which work on detection and imaging of infrared radiation is being carried out.

The Director of S.E.R.L., Dr. M. H. Oliver, visited the Philips International Research Exhibition at Eindhoven on October 31st.

Mr. H. Foster attended a one-day Conference on Professional Management at Stevenage on November 12th.

Mr. A. Crocker visited France during the period 18th - 20th November to attend an International Symposium on Lasers and an associated exhibition of laser equipment.

Dr. C. H. Gooch attended the I.E.E.E. Semiconductor Laser Conference in Mexico City in November, and visited a number of American firms working on semi-conductor electroluminescent devices.



Brittle Fracture Handbook

Arrangements have been made for the work of the Navy Department Advisory Committee on Structural Steel on "Brittle Fracture in Steel Structures" to be published by Butterworth & Co. (Publishers) Ltd.

This book will present a unique attempt to give sound practical guidance to design engineers and others concerned with the construction of large steel structures. There is little doubt that the many catastrophic failures which have occurred in the past and which are recorded in this manual could have been avoided if designers had had access to and had followed the guidance now given.

Release is expected to be on the 27th May, 1970.



NATO Advanced Study Institute

The NATO Advanced Study Institute is to hold a course on Computer Based Learning in Training Systems Design at the Royal Naval College, Greenwich, from 19th April to 1st May, 1970.

Applications for the course should be made to the Dean of the College, not later than 23rd February, 1970.

Book Reviews

Introduction to Modern Mathematics. By H. Meschkowski. Pp. vi + 191. London; George G. Harrap, 1968, Price 27s. 6d.

Modern mathematics as outlined in this book is the theory of formal structures. The theories are applied particularly to develop a theory of real numbers, complex numbers being excluded. The book is an introduction to the subject for young undergraduates and is an excellent introduction, being a translation of a German text first published in 1964.

The central theme of the book is the use of the axiomatic approach, the history and essentials of which are well brought out in the first chapter. Here, as well, the discovery of non euclidian geometry and the formalism of Hilbert are outlined. Using the axiomatic approach a number of mathematical structures are

built up and these are used to develop a theory of real numbers in a way which has some novelty. The main structures are sets, groups, rings, fields, lattices and spaces.

Set theory, which stems from Cantor, was upset by Russell but as the book explains most of the difficulties can be resolved and it is now a corner-stone of modern mathematics. In the chapter on sets the usual topics of intersection and union of sets, functions (mapping) and ordering in sets are discussed as well as the use of logical symbols and their truth tables. The concept of Cantor's cardinal number of a set is introduced and its application to transfinite numbers explained. Order sets are important theoretically and are introduced in the book axiomatically but with ample examples leading to the ideas of well ordered sets. Partially ordered sets are later discussed in the chapter on lattices.

Group theory, although it may not have maintained the promise of its youth, is still useful in modern mathematics. The book introduces the subject gently via symmetry and permutations before plunging into formal definitions and investigations of their properties such as complexes, co-sets, and sub-groups.

The book discusses rings and fields which are algebraic structures of some importance. In these structures two binary operations are used which are generalised analogues of addition and multiplication in arithmetic. The subject is again developed formally and in a short chapter the elementary properties of commutative and non-commutative rings are deduced and a simple introduction to congruences given.

A chapter on lattices is perhaps unusual in an English mathematical text book but the origin of the book is German. The book approaches the subject by simple examples from modern graph theory leading again to the formal definition of a lattice. Two binary operations are involved and although these can be any two abstract operations only simple examples are used to illuminate the theory. The principle of duality can arise between the two operations and examples of specialised lattices such as distributive lattices are given to illustrate where the principle applies. The fruitfulness of lattice theory lies in its many applications to a wide range of topics as diverse as elementary number theory, projective geometry, and the propositional calculus.

Of the large class of theories of spaces only simple metric and topological spaces are discussed. The chapter on spaces deals mainly with the concept of a filter and in particular a Cauchy-filter by means of which the field of numbers is extended to include all real numbers. Earlier in the book the concept of number is enlarged to contain negative integers, rational numbers (defined by an ordered pair of integers), and finally the filter concept allows the inclusion of all real numbers. The filter concept replaces the older Dedekind method well known to all the older generations of mathematicians. Whether this new approach will be adopted widely in the future only classroom experience can answer but the author of the book argues strongly in its favour.

The last chapter on real numbers also has an interesting introduction to unsolved number theoretical problems such as those concerned with the possible occurrence of the ten digits in their natural order in the decimal representation of a real number such as e.

The book is an excellent introduction to the elementary theory of numbers from a modern standpoint and also to modern mathematical structures. The ground work is always well established before any abstraction is made and this is essential in any "introduction" to a subject.

R. A. M. Bound

Thermodynamics. By William C. Reynolds. Pp. xiv+496. London; McGraw-Hill Book Co., 1968. Price 105s. 6d.

This is the second edition of an excellent book first published in 1965 with the intention of providing a fundamental first course for engineers. It employs the increasingly popular approach (see *Thermostatics and Thermodynamics* by Myron Tribus 1961; D. Van Nostrand Co. Inc.) of developing macroscopic thermodynamics through a study of the microscopic conceptual theories, but it takes care not to lose the student in a welter of quantum mechanics and statistical theory. The author recognises that most engineering students nowadays possess a good insight into the microscopic world as a result of their basic physics courses, and usually have a working knowledge of quantum concepts, and he therefore takes this into account and where necessary reinforces this basic knowledge; whilst randomness-uncertainty ideas have been woven throughout the text, two chapters, 12 and 13, deal more extensively with the statistical and kinetic aspects of matter. Chapter 6 probably contains the most significant change from the first edition in that it discusses entropy and the second law of thermodynamics on the basis of the Gibbs definition in terms of the probabilities of the system quantum states, whereas the earlier edition employed the Boltzmann approach to entropy.

The arrangement of this book, as well as its approach, appeals to the reviewer, in that the opening chapter sets the scene with a fresh look at fundamentals, and introduces concepts, laws and models, the second chapter studies energy and the first law, the next two chapters deal with properties and states, and Chapter 5 consolidates by examining the energy analysis of thermodynamic systems, before leading into the next chapter described above. The consequences of the second law are analyzed in Chapter 7, and the next chapter looks at the thermodynamics of state, whilst Chapter 9 again serves a most useful consolidation purpose in examining the characteristics of various thermodynamic systems. The remaining chapters cover thermodynamics of non-reacting and reacting mixtures, investigates some aspects of molecular kinetics and concludes with an introduction to irreversible thermodynamics.

The book is well produced, excellently printed and contains many clear illustrations. It is supported with two thorough Appendices relating to unit systems and dimensional equivalents, and the thermodynamic properties of an extensive range of substances, respectively. Each chapter contains an adequate list of selected references, and a useful number of very good examples.

J. Edwards

Applications of Critical Path Techniques. Edited by Jas. Brennan. Pp. 247. London; The English Universities Press Ltd., 1968. Price 105s.

This book reports the Conference on Applications of Critical Path Techniques held in Brussels in 1967 under the aegis of the N.A.T.O. Scientific Affairs Committee. It reproduces all of the papers presented in the five sessions, together with the discussions, and does this with the aid of explicit printing and generally good diagrams and flow charts. The latter however tend to suffer in some instances as a result of fade-out of flow lines, and some illegibility of captions, although this almost certainly arises from the poor quality of the originals.

The undoubted value of the Conference, and therefore of this book, is that a useful number of well tested applications of Critical Path Techniques are fully and carefully presented, and furthermore, their weaknesses and limitations fairly faithfully analyzed by the authors.

There are sufficient books on the basic principles of network analysis about to satisfy most needs, but good solid examples of actual modern applications are harder to find, and the book provides a sufficient assortment of these to be of considerable use to anyone either in the field, or wishing to apply CPT for the first time to his own problems.

Twenty-three papers were presented at the Conference and a selection from the titles will probably provide as good a way as any of defining the interests. These range from: "C.P.M.s used by M.P.B. & W. and its contractors", "C.P.T. applied to Dungeness 'B' Nuclear Power Station", "C.P.T. applied to Petro-Chemical Plant Maintenance Shut-downs", "The use of C.P.T. in a joint Government/Industry Development Project", "Project planning and control in Norwegian Shipbuilding using activity orientated network programmes", "Production Control using resource allocation techniques in a fabrication shop", "The planning network as a basis for resource allocation", "Cost planning and project profitability assessment", and "The use of network analysis as an aid in the selection, planning and control of research and development projects". There were also papers relating to future developments in network planning by computers.

In the reviewer's opinion, critical path techniques are very far from being as popular or as widely used as they should be, and this applies to all levels of management and to all sizes and types of project. The present book may do something to remedy this situation, and is recommended as a good purchase to all who may be concerned in any way with management decision making and project control.

J. Edwards

Analogue Computers. By K. N. Dodd. Pp. 191. London; The English Universities Press Ltd., 1969. Price 10s.

This is an excellent little book in the Teach Yourself series and represents, as is usual, very good value for money, even though in the reviewer's opinion, it devotes too little space to the use of analogue devices in actual scientific computing, or analytical roles, viz., in systems analysis and design. Despite this, however, it remains an extremely readable book, with beautifully lucid explanations, a logical and easily followed development and well selected illustrative examples. It pre-supposes practically no mathematical knowledge on the reader's part, and manages to deal competently with this aspect in 18 pages. It then takes the reader through early analogue devices from the astrolabe and slide rule to the governor, planimeter, integrators and differential analysers. The next chapter covers computing mechanisms and the symbolism used in circuit notation, and chapter four considers the electronics and components of circuits used in analogue computers. The three following chapters cover servomechanisms, servo applications and gyroscopic instruments, and good use is made of practical examples in common use and readily understandable to the layman. Chapter eight uses automatic flying and landing aids to illustrate how the techniques previously described are brought together, and chapter nine discusses—but in a limited fashion—modern applications of analogue computers. Chapter ten discusses the basics of analogue to digital conversion, and just mentions hybrid computers, and the final chapter provides a fundamental account of fluidics and its potential applications.

This is a most useful pocket book for the layman and matches up well to the high standards of the Teach Yourself series.

J. Edwards

Introduction to Control Theory for Engineers. By A. Sensiele. Pp. 246. London. Blackie and Sons, Ltd. 1968. Price 40s.

The author has produced an introduction to this complex subject which is to be highly recommended to all who are concerned with control engineering. A system of asterisk marking of sections enables the reader to obtain the background by reading in sequence the sections so marked. The other sections and chapters can then be digested as required.

The first chapter includes an introduction to block diagrams and the transfer function of a remote position control system and although not exhaustive serves as a useful introduction to the methods used throughout the book. The next chapter illustrates the use of operator methods in solving control system differential equations, and the "P operator" is employed in the text and worked examples. The examples at the end of this chapter are well chosen. The Laplace transform is explained in the usual way in Chapter three with some more useful worked examples. The next chapter is devoted to an examination of a practical remote position control system, and the reader is gently introduced to the interpretation of systems performance in terms of the damping ratio for an input step function. Stability and linearity are briefly touched on.

The chapters on System Analogues and Analogue Computing Units, and the practical use of Analogue Computers, are conventional but necessary to complete the authors stated intention of providing an introduction to the subject. These chapters also provide a basis for experimental work and further study of linear systems.

Next the root locus pattern, how the shape can be used to indicate a system's performance, and how the system may be improved by changes to the root locus pattern and the methods of change. The open-loop frequency response is examined by the three usual methods, Nyquist stability criterion, Bode diagrams, and Nichols chart. The Routh-Hurwitz method of establishing whether a system is stable or not by finding the condition under which the characteristic equations have roots with only real negative parts is dealt with, but no emphasis is placed upon the difficulties of establishing algebraic criterion for the degree of damping. In chapter 10 the reader is shown by worked examples how, by using the graphical methods of the previous chapters it is possible to design a system by analysis. The adjustments which can be made by passive lag and lead compensation networks and the effects on the Bode diagrams and Nichols charts are well illustrated. The feed-back compensation is briefly mentioned and the reviewer feels that an additional worked example pointing out some of the difficulties of feed-back, as against feed forward, compensation would have been very useful.

The last chapter and appendix are an excellent introduction to non-linear systems. The relay controlled system is briefly covered and a method of using the describing function of a non-linear element to analyse the frequency response is considered. The phase-plane method is extended to describe a given system and the method of isoquines is explored.

This book is well printed and presented, the diagrams are clear and relate to the immediate text. The author is to be congratulated for writing a good textbook which should be helpful to many people who are, or will be, concerned with control engineering.

R. Forse

Large Scale Provisioning Systems. By Editor J. Ferrier. London; The English Universities Press Ltd., 1968. Price 126s.

This volume records the Proceedings of an International Conference held in Athens from 4th to 8th September, 1967 under the auspices of the N.A.T.O. Scientific Affairs Committee. The theme of the conference was "The Applications of Operational Research to Large Scale Provisioning Systems".

There are 29 papers from eight different countries, the U.S.A. providing the majority of the authors but contributions came also from Norway, Greece, Turkey, France, Germany, Canada and the United Kingdom. The delegates came from 14 different countries, including some outside N.A.T.O.; a truly international conference!

The papers are reproduced in the language in which they were presented, either English or French and apart from the foreword, translations are not provided. However abstracts (or résumés) are.

The conference had nine sessions:—

Opening Session with a paper on "Managers Scientists and Systems" by Robert G. Brown of the Operational Research Section of Arthur D. Little Inc. (U.S.A.).

Session II: Forecasting.

Session III: General Concepts and Problems.

Session IV: Transportation Problems.

Session V: Theoretical Studies in Inventory Management.

Session VI: Practical Studies—Recoverable Items.

Session VII: Practical Studies — Non-recoverable Items.

Session VIII: Practical Studies — Evaluation, Cost Effectiveness.

Session IX: The Analysis and Simulation of Large Scale Logistic Systems.

The above shows the scope of the conference. Any one concerned with the management of provisioning systems will find much that is interesting and stimulating not least the comments in the discussions of each session.

The subject matter is complicated and many of the papers inevitably make extensive use of mathematics. The application of mathematics to logistics involves assumptions about distribution of demands. This raises the question as to why particular distributions are chosen; because they fit the data available or because they ease the analysis? However there is no doubt that the operational research approach to logistics is valuable and takes some of the guess-work out of decision-making.

Some of the proposed systems seem to result in too much complexity and while they may result in optimum theoretical answers one feels that a simpler system perhaps less optimized, may give better results in practice. The success of the two-bin system in the R.N. is an example of a very simple system which has worked most effectively in practice. In this system the item is stored in two bins and replenishment takes place when one bin becomes empty; simple and effective!

I recommend this volume to all who are concerned with military provisioning systems.

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Illustrations are in most cases a desirable addition. Photographs should be of good quality, glossy, unmounted, and preferably between two and three times the size of the required final picture. Graphs and line drawings should be made on a similar large scale, with bold lines to permit reduction in block making.

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